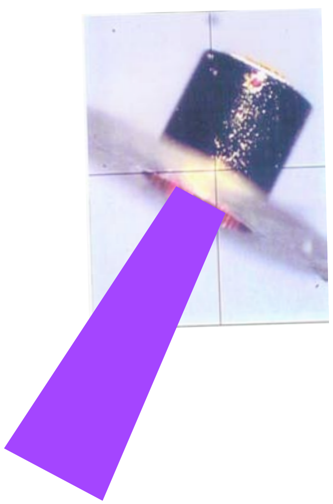
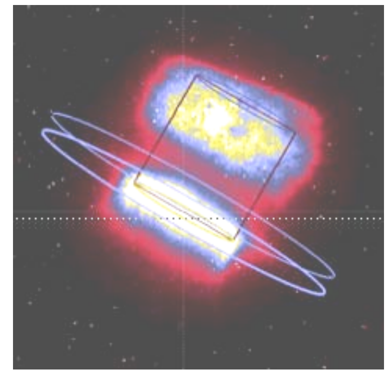
An Overview of LLNL Experiments Relevant to Opacity Code Validation

Presented to
Los Alamos Opacity V&V Workshop



Physics & Advanced Technologies
V Division

Physical Data Research Program
Nuclear•Atomic•Condensed Matter Physics



Robert F. Heeter

May 4, 2005

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

LLNL has revitalized its opacity experimental efforts in anticipation of breakthroughs on NIF and PWs

2. "Long-Pulse" experiments at Omega and NEL ("NIF Early Light")

- Design Calculations + Theory: hot hohlraums, opacity targets, foil samples
- Capability Development Experiments:
  - Spectrometers, Backlighters, NEL commissioning & Hot Hohlraums
- Code Physics Validation Experiments: Gd-Al transmission measurements
- Rosseland Mean Experiments: working towards Ta (etc.) at T_r > 100 eV
- One long-range goal: very high T_r, high-Z LTE experiments on NIF

1. "Short-Pulse" experiments at LULI, COMET, JanUSP, Vulcan-PW…

- Absorption spectroscopy of fs-heated warm dense matter
- Emission spectroscopy of ps-heated hot dense matter
- High-intensity laser-matter coupling studies (backlighters, ps hohlraums)
- Pushing proton heating to higher T for, e.g., solar opacity experiments
- One long range goal: high density, high-Z LTE experiments on PW's

This talk presents a (non-representative) sample of our unclassified work: Short-pulse, NIF and NEL, Hot Hohlraums, Omega capability development

My own roles are highlighted in red

We are currently collaborating with LULI in measuring transmission in low temperature, high density short pulse laser heated matter

Research Team

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Summary follows; for more details: *Phys. Rev. Lett. 94, 025004 (2005)*

Viewgraph courtesy of Ronnie Shepherd

Conceptual layout of the experiment

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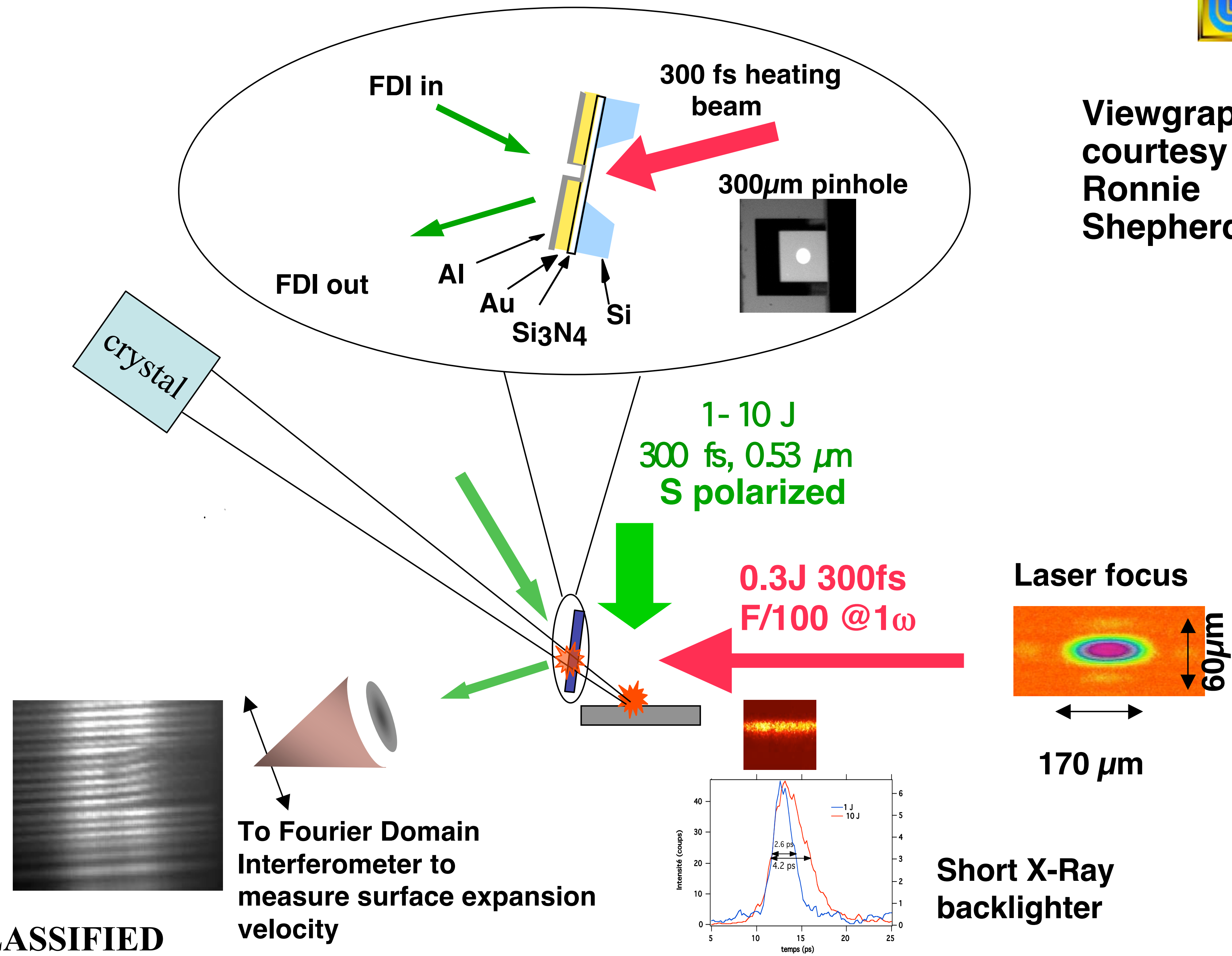
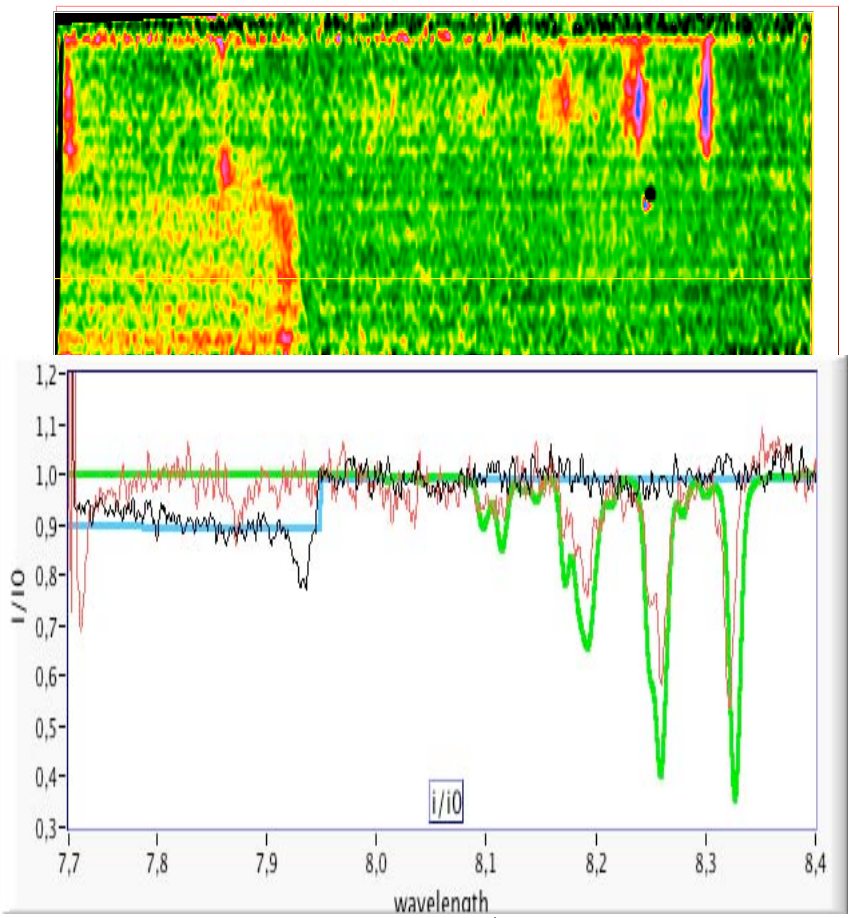


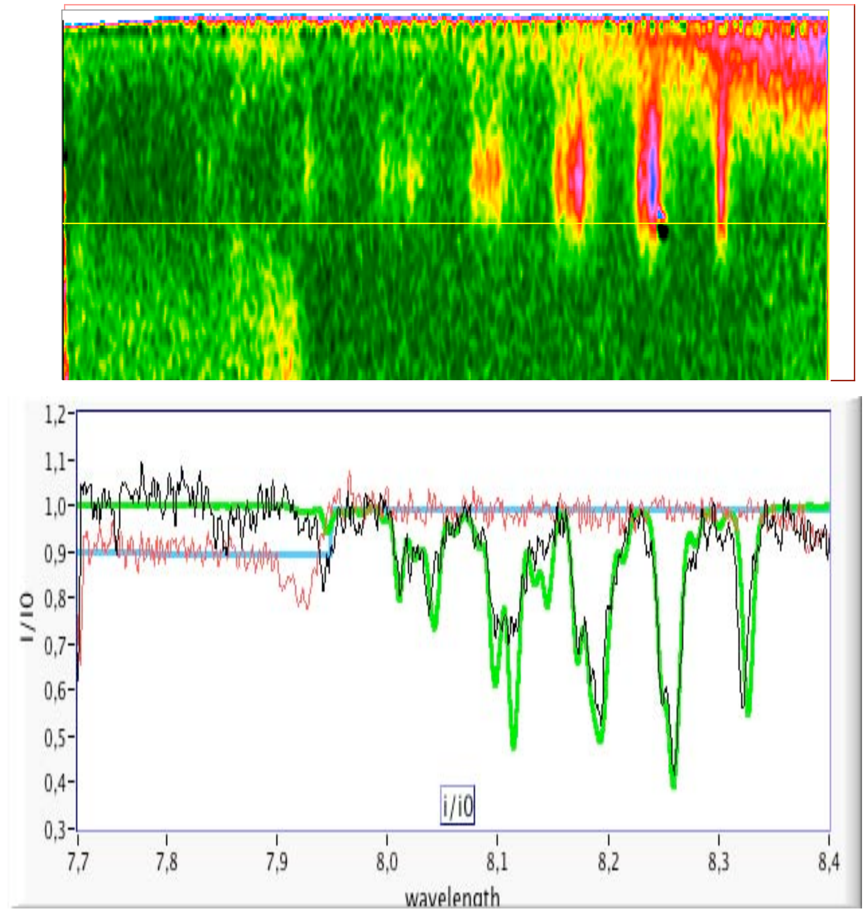
Viewgraph courtesy of Ronnie Shepherd

Short-pulse (3 of 4):

Data suggest the absorption spectra can be fit using two calculated LTE spectra, keeping the experimental ρl constant



I=3 10^{15}w/cm^2, x=830 Å Al, t=to+7ps

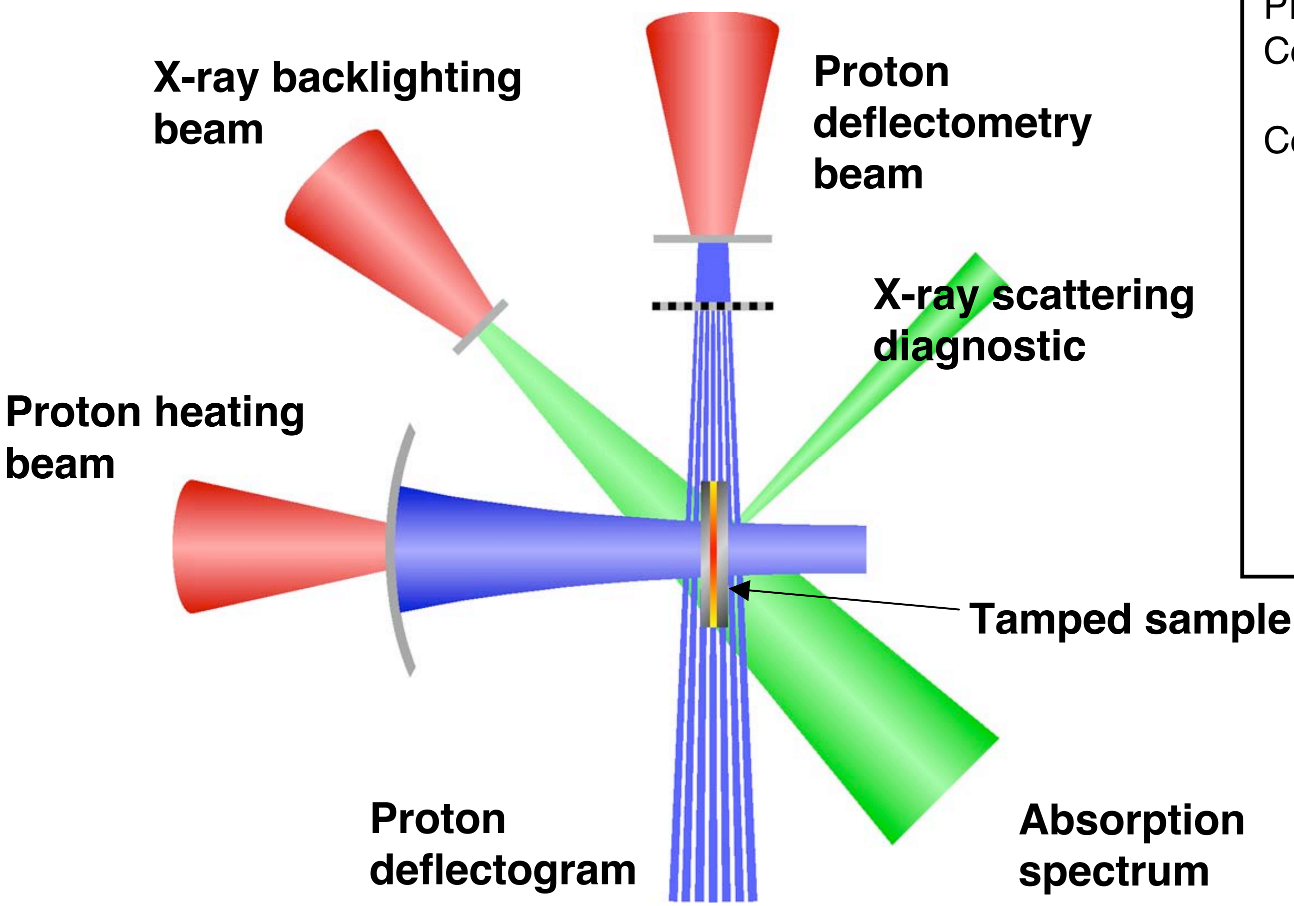


I=3 10^{15}w/cm^2, x=830 Å Al , t=to+3ps

Well-characterized isochorically-heated matter is an increasingly promising direction for opacity validation experiments

Viewgraph courtesy of Ronnie Shepherd

An LDRD effort seeks to build a new platform for Opacity on PW-class lasers, using proton heating



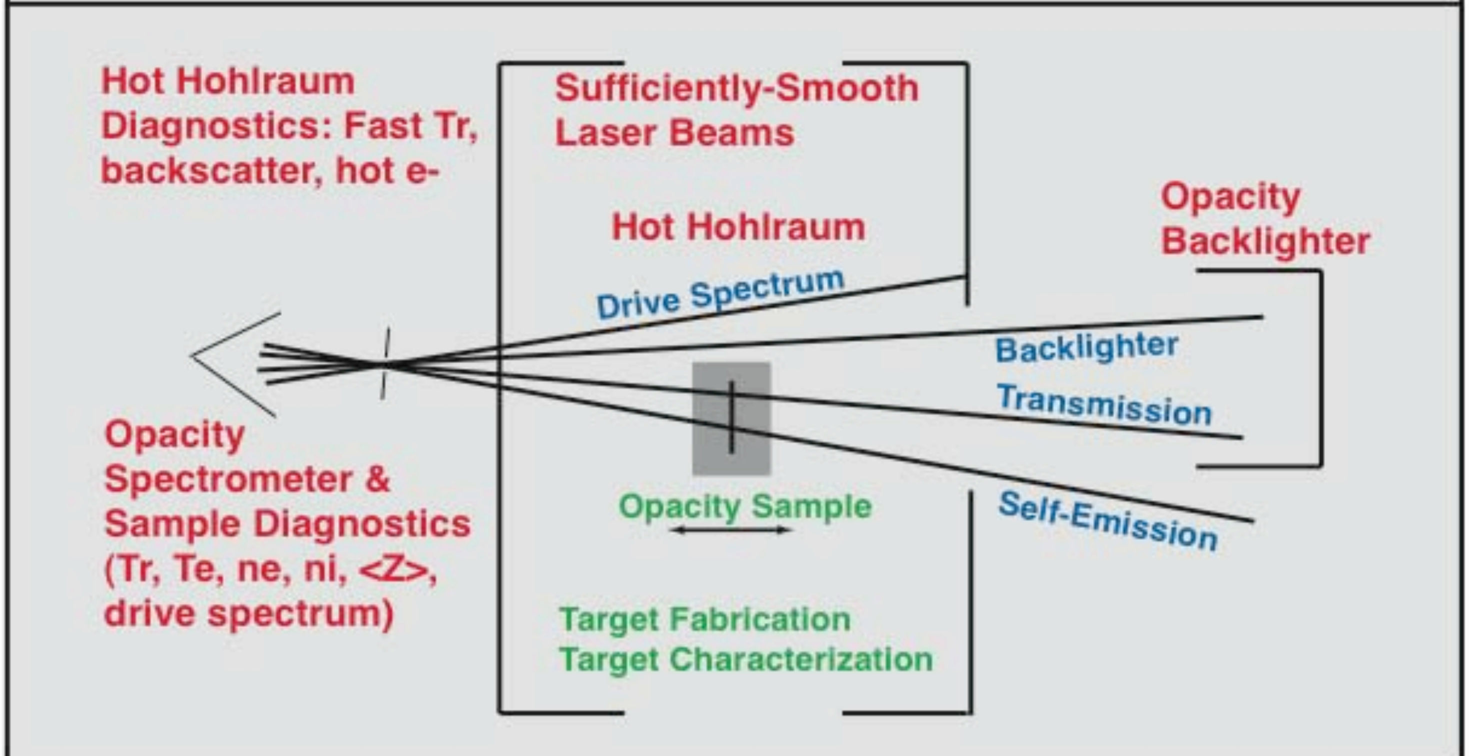
PI:	Prav Patel (PAT)
Co-Pis:	Richard Town (DNT), Andy Mackinnon (NIF)
Co-Is:	Bob Heeter, Carlos Iglesias, Mark Foord, Ronnie Shepherd, Scott Wilks (PAT); Gianluca Gregori, Rich Snavely (NIF); Marco Borghesi (Queen's Univ., Belfast, UK)

Plan is to apply an array of old and new short-pulse techniques to tackle the challenge of measuring opacities in high energy density plasmas

Viewgraph borrowed from talk by Prav Patel

Capability Development efforts derive from elements of a large-laser Rosseland mean experiment

Anatomy of typical hohlraum-based opacity experiment (not to scale)

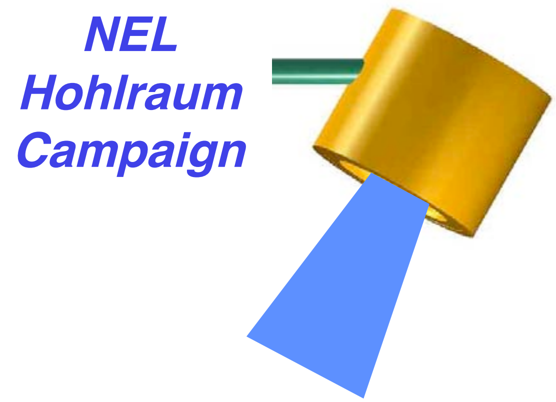


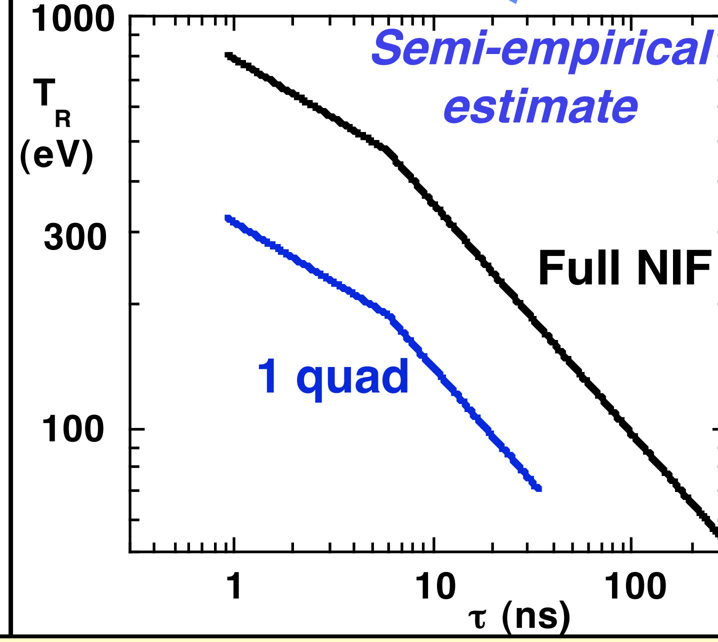
Opacity = - (ℓn [(Transmission - Emission) / Backlighter]) / ρL

These are extremely challenging experiments - many high-performance components must work simultaneously

NIF will revolutionize LTE transmission opacity experiments… eventually

- The NIF Basics:
  - 192 beams (48 “quads”)
  - GOOD: 1 quad deployed in FY04:
    - NIF Early Light (NEL) experiments
    - Max power ~ 9 TW/quad (9 kJ in 1 ns)
    - Scales to 432 TW; expect ~750 TW (Omega: 30 TW)
    - Core diagnostics deployed (Dante, framing cameras, backscatter...)
    - Results coming up on following slides…
  - BAD: No user shots in FY05-FY09
  - UGLY: No HED experiments until FY11 (ICF ignition campaign in FY10)
- Utility for Opacity Experiments:
  - Scalings suggest very high T_r is possible
  - At lower T_r, can do larger, better experiments

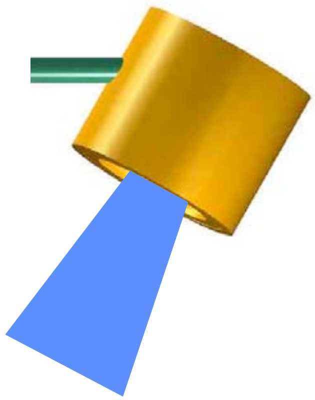


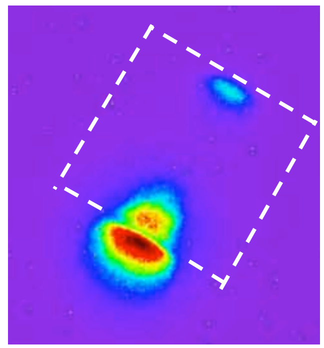


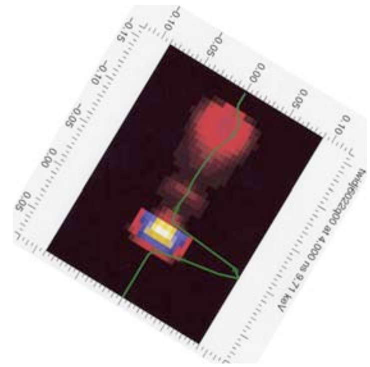
Our Plan: establish NIF-portable capabilities at Omega; much to do by FY11!

First hohlraum experiments on NIF

-Long Pulse Vacuum Hohlraum Performance on NIF







E. Dewald, O. Landen, L. Suter, K. Campbell, J. Schein, M. Schneider, J. Holder, C. Niemann, S. Glenzer, B. Young, J. McDonald, R. Turner, F. Weber, D. Lee, M. Landon, A. MacKinnon, D. Froula, S. Dixit, C. Haynam, B. Hammel, R. Kauffman, J. Celeste, J. McDonald, R. Wallace

Lawrence Livermore National Laboratory, Livermore, CA

J. Foster (AWE), B. Thomas (AWE), D. Chambers (AWE), R. Stevenson (AWE), M-C Monteil (CEA), J. Fernandez (LANL), J. Kline (LANL), R. Olson (SNL), R. Leeper (SNL), G. Rochau (SNL)

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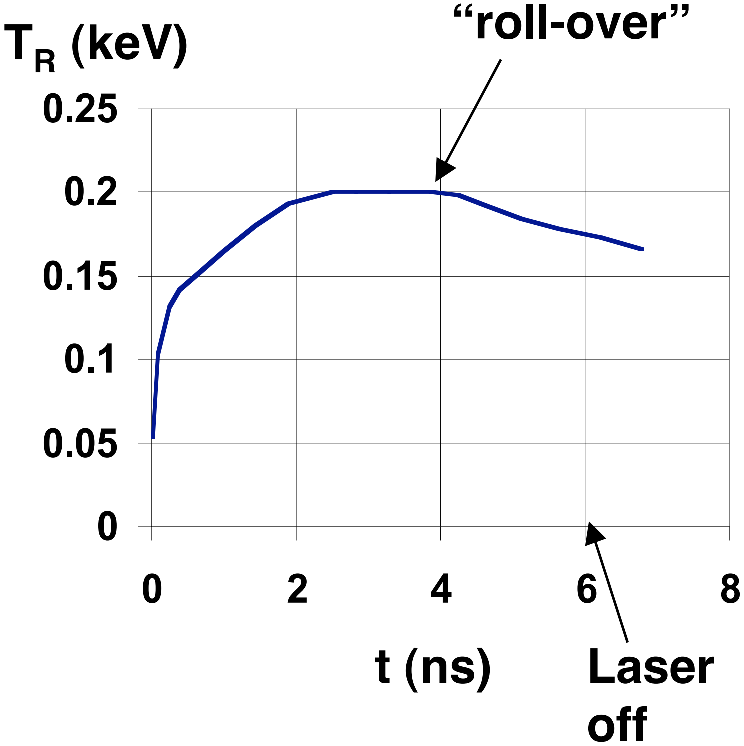
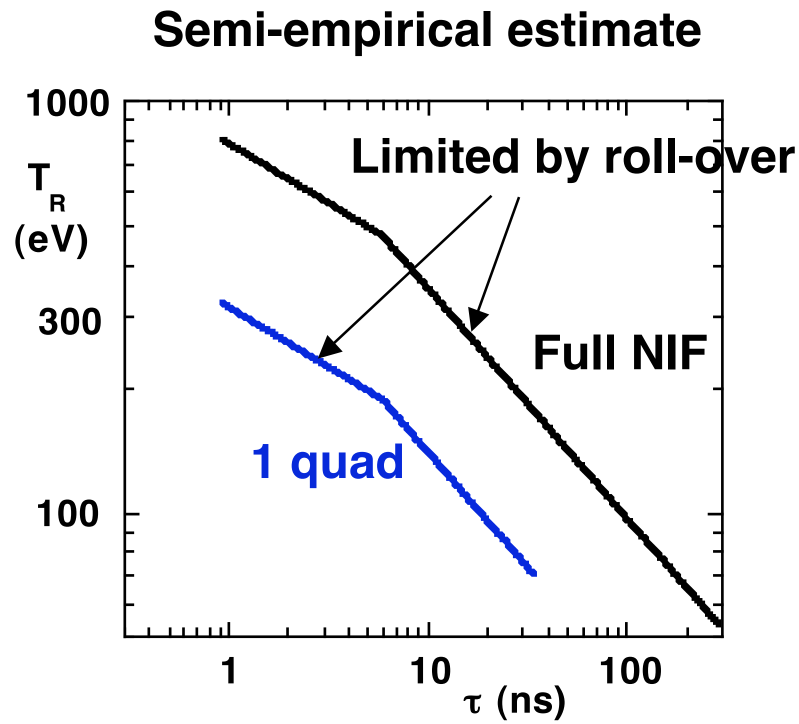
In 1995 Brian Thomas (AWE) developed a "T_R-τ" metric for assessing a laser's utility for HEDS

Basic idea: plasma filling leads to a maximum time that a given hohlraum, irradiated at a given power, will work

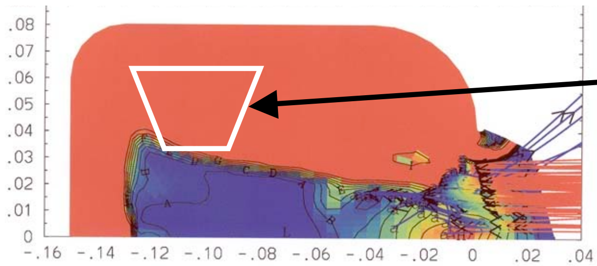




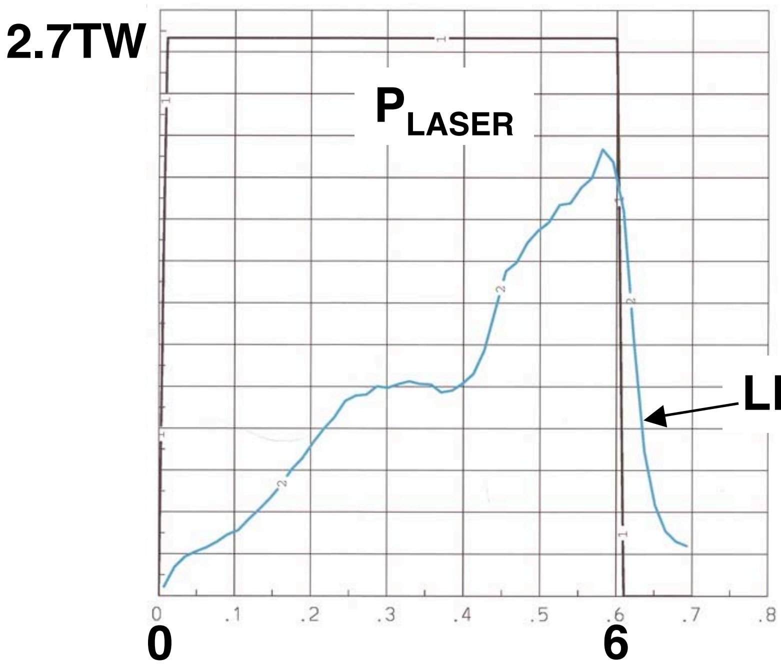
The T_R-τ plot allows estimates of potential HEDS experiments

- **However, what physically limits maximum time is debatable**
- **School 1: LPI fiasco when can fills such that n_e>$0.1n_c$**
- **School 2: Roll-over when can fills so laser depo moves to LEH**

The internal T_R in our simulated experimental volume rolls-over for two reasons



1- Experimental volume's view of source becomes obscured by blow-off
(can be fixed to some degree)



t (ns)

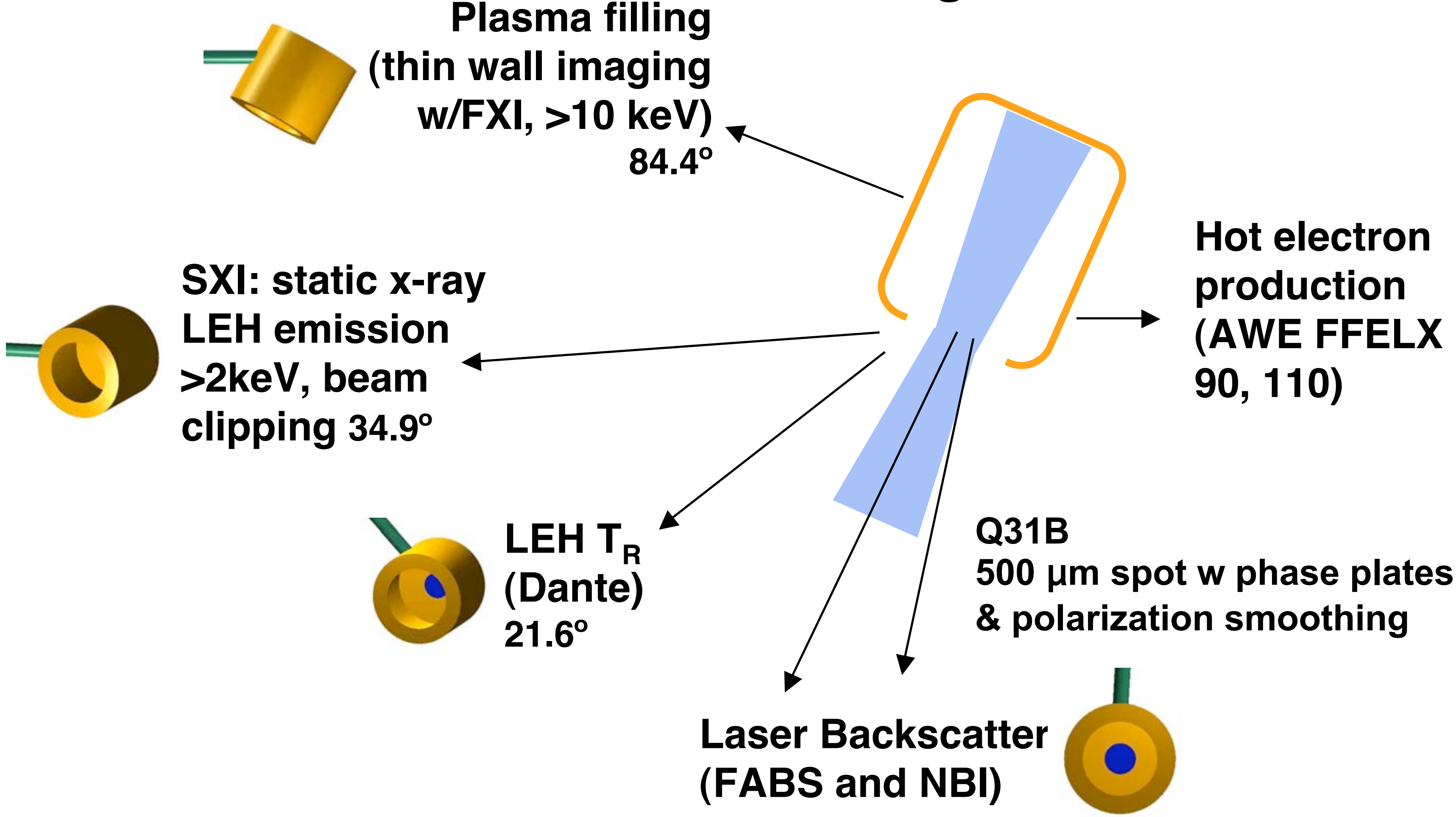
2- Plasma evolution causes laser deposition and rad production to move toward LEH
Rad losses from LEH rise

Objectives of Sept. 2004 NEL shots: Establish NEL as hohlraum physics facility, at ignition relevant T_R's, and understand T_R-τ limits (Thomas plots) for halfraums

We shot 7 Vacuum hohlraums (5µm Au backed by 100um CH) and studied plasma filling via hard x-ray imaging

NIF
The National Ignition Facility

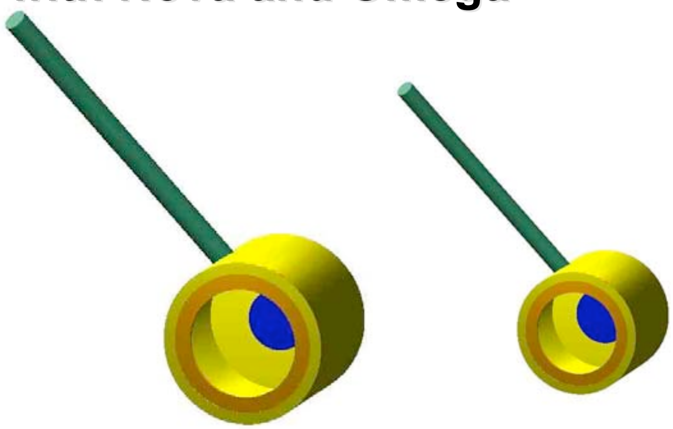
Diagnostics:



Hohlraum size: scales ¾ (1.2 mm diameter) – 1.5 (2.4 mm diameter)

We really did two series; a power scaling with 2ns flattop pulses and a filling series with 6 to 9ns flattop pulses

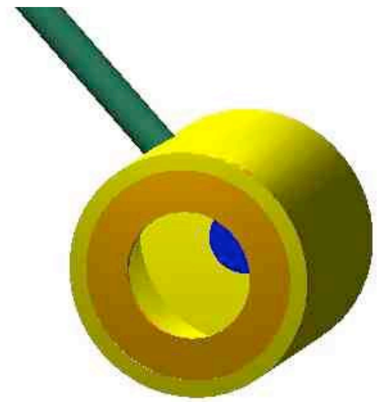
2ns POWER SCALING these provided the best "contact" with Nova and Omega



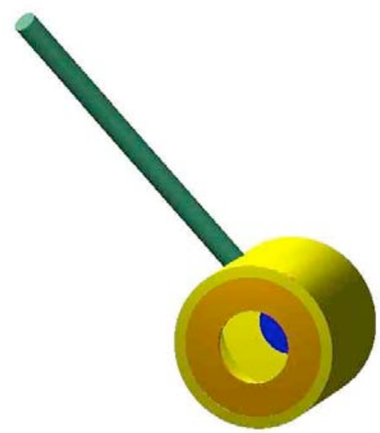
Scale 1 (3/4), 75% LEH; ~5, 9 & 13kJ

All used a 500um diameter spot smoothed by CPP+PS

LONG PULSE EXPERIMENTS (6-9 ns) provided "very filled" info

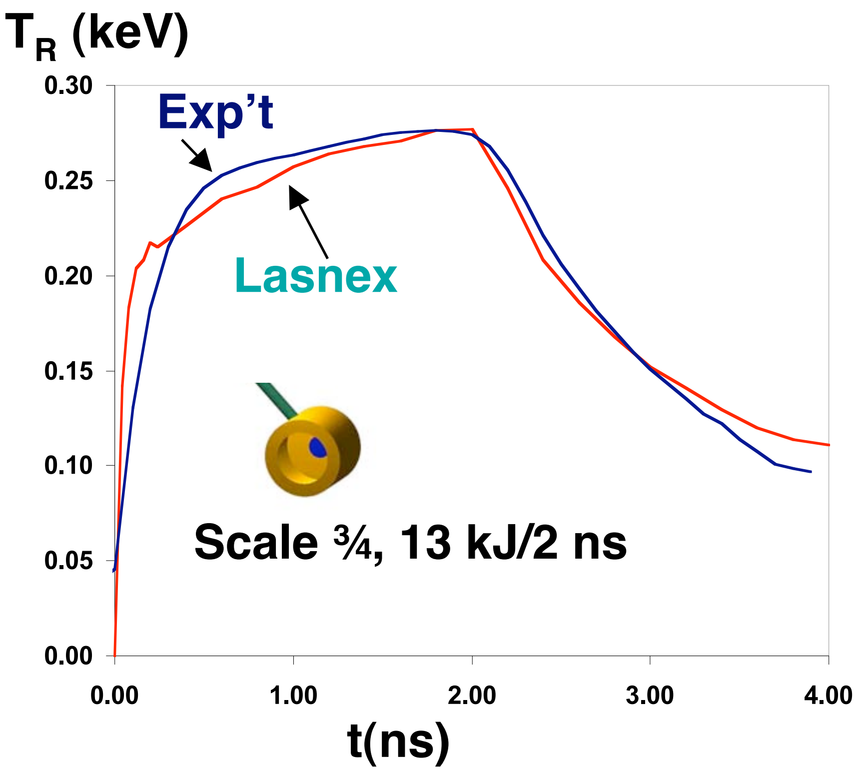


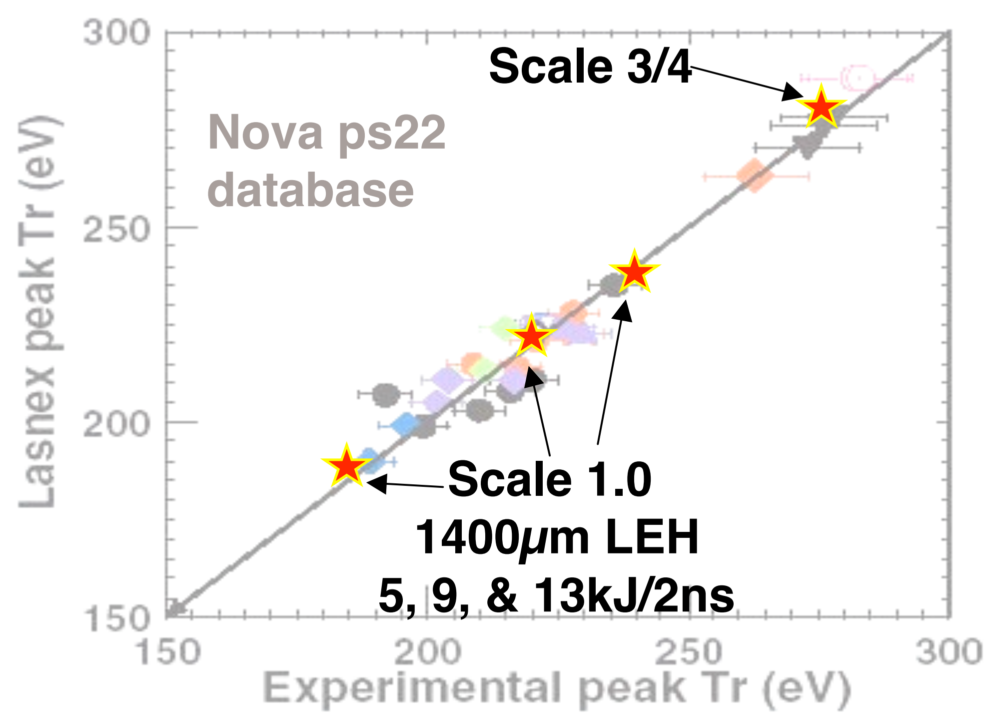
Scale 1.5 with a 1.4 mm LEH



Scale 1, 50% LEH

The 2ns power scaling showed hohlraum T_R essentially follows predictions





- **Low laser backscattering** - scale 1: <0.05%SBS, negligible SRS,
  scale ¾: <0.5% SBS, ~0.05% SRS
- fhot very low (<0.2% for scale 1, ~1 % for scale ¾)

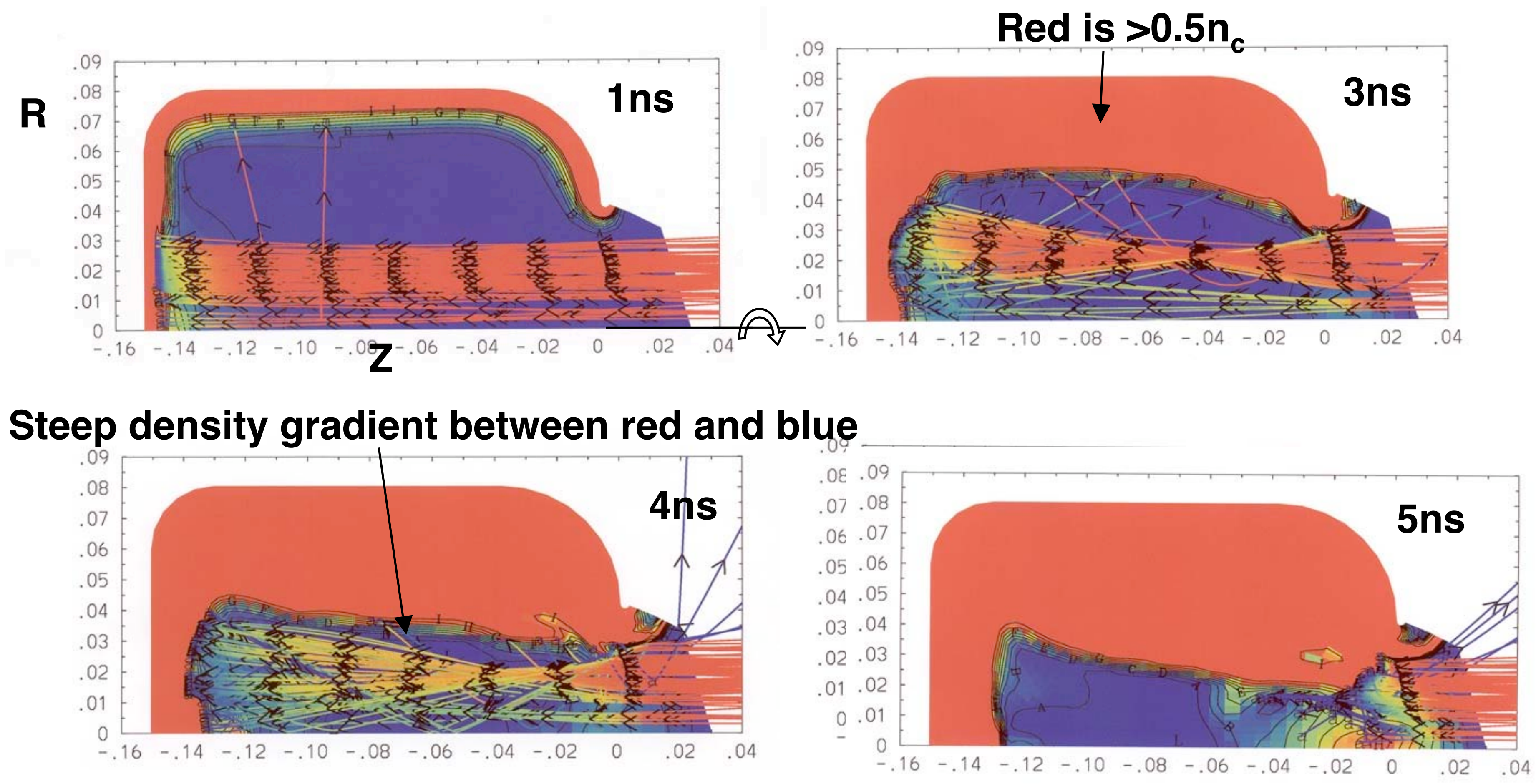
The longer pulse hohlraums explored the T_R-τ limits (Thomas plots) for halfraums

NIF

The National Ignition Facility

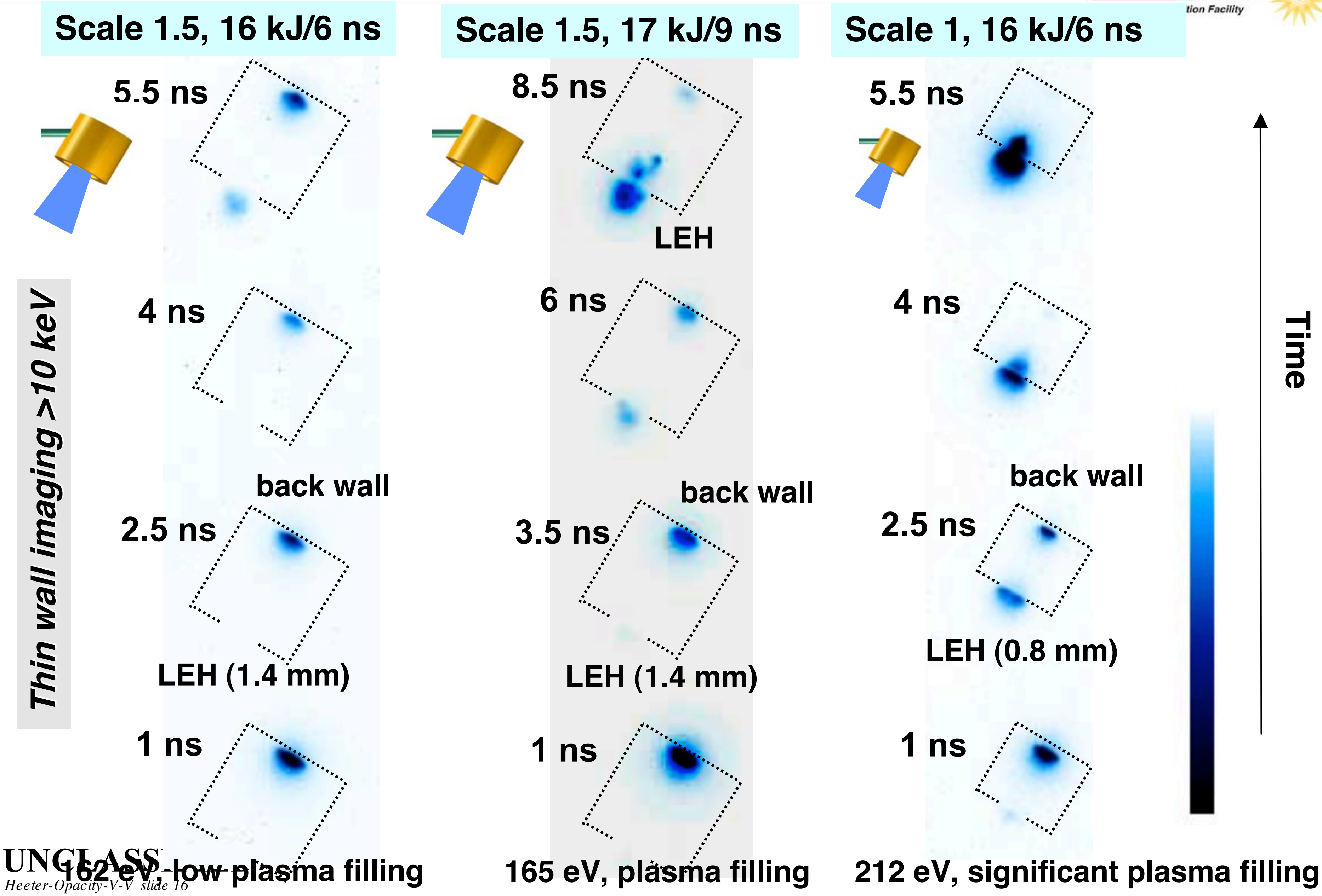
This shows the dynamics of a scale 1.0 heated by a 6ns pulse

- **The high pressure of the laser heated channel keeps it open**



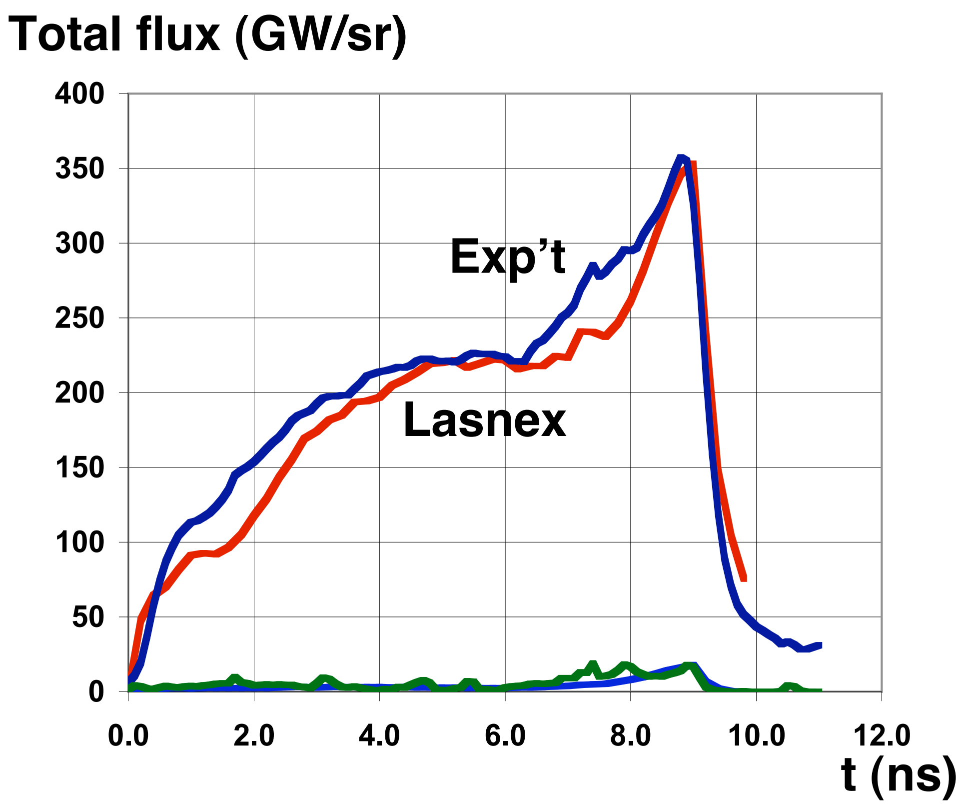
Color indicates electron density: Red=high Blue=low

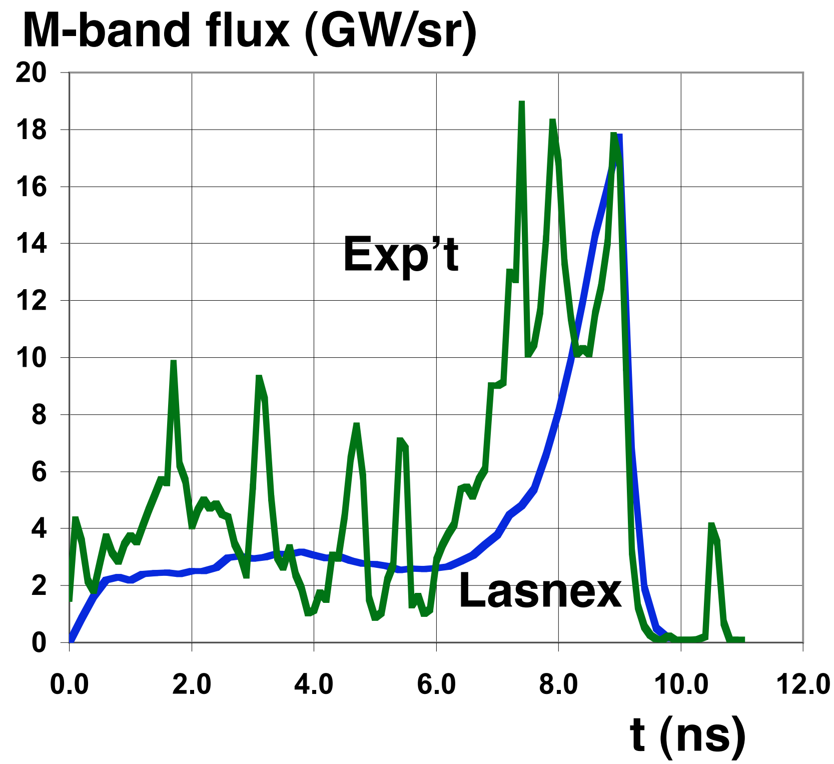
Thin wall imaging clearly shows laser deposition moving to the LEH with longer pulses as the hohlraum fills with plasma



The temporal behavior of x-ray flux, as well as thin-wall imaging, is consistent with our predictions of late time filling

Scale 1.5, 17 kJ / 9 ns





- **The marked rise in total x-ray flux and M-band occurs when the deposition moves to the LEH**

- **Low laser backscattering - <0.5%SBS, <0.05% SRS**
- **fhot very low (<0.3 %)**

Late rise in Dante flux, correlated w/ hard x-ray emission shift to LEH, supports models of extreme plasma filling

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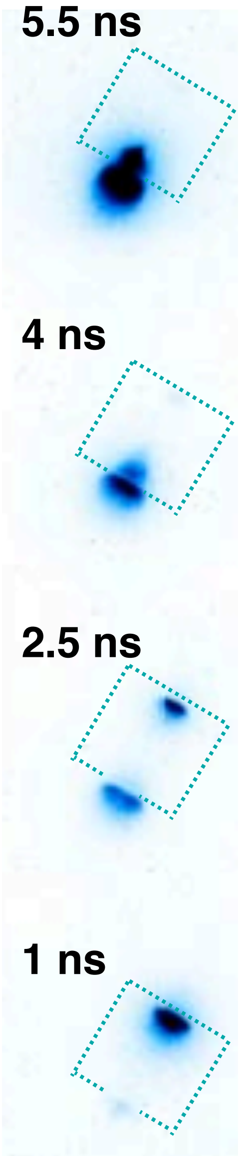
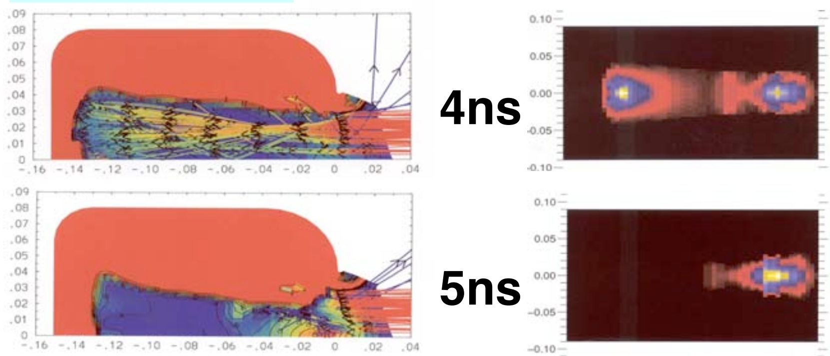
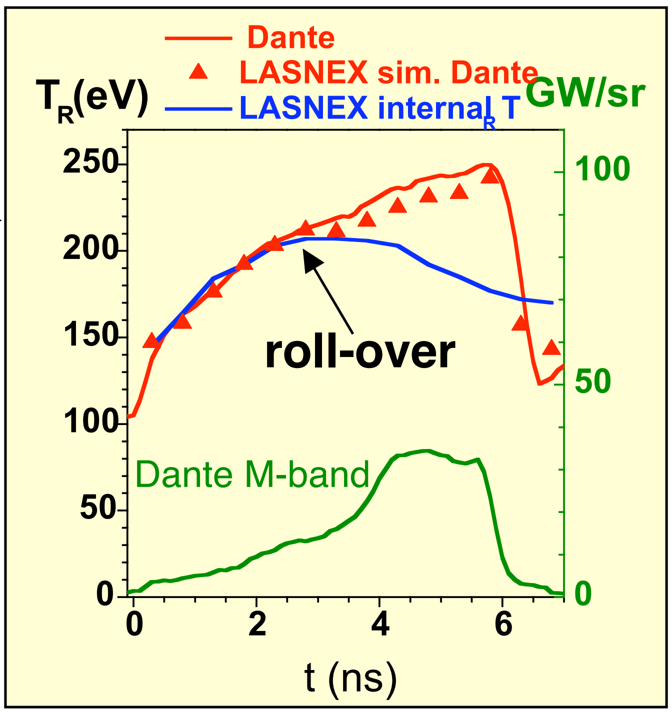
Scale 1, 16 kJ/6 ns

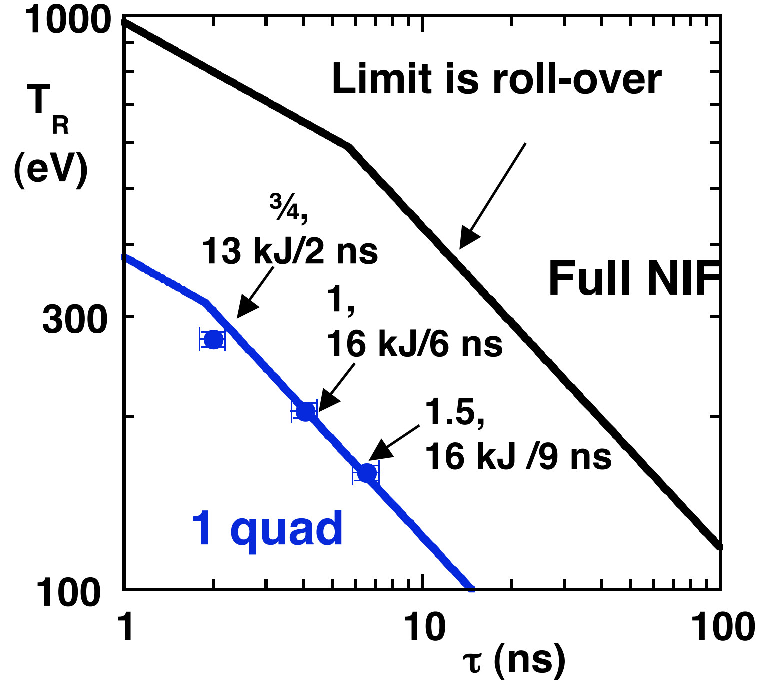


Simulation



Data





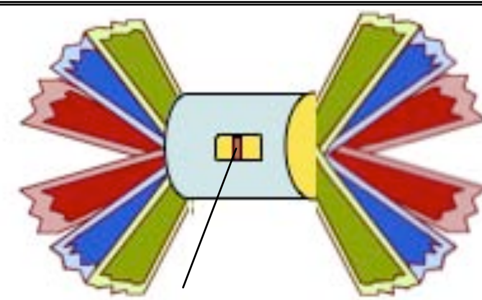
● NEL hohlraum data

This work is now in Review-Release for submission to PRL (E. Dewald et al.)

The Hot Hohlraum (HTH) campaign seeks to produce hot radiation environments for weapons physics studies

- Weapons physics at full NIF requires high T_{rad}
  - Different physics regime than ICF
  - Ongoing HTH campaign at OMEGA laser
- The NIF experiments were a collaboration with ICF
  - Simple geometry helped HTH
  - Extended parameter space helped ICF and NIF
    - Diagnostics • Pointing/Positioning • Timing

T_{rad} (HED)> T_{rad}(ICF)



NIF Hohlraum and Gas-Tube Campaign

Principal Investigator, Experiments:

Nino Landen, *Associate Program Leader for Ignition Physics Experiments*,

Principal Investigator, Theory:

Larry Suter, *A/X Division (DNT) and Ignition Target Leader, ICF (NIF)*

21 shots into Target Chamber in 11 days

NIF Project Diagnostic Division Leader: Brian MacGowan

HTH helped collaboration by exercising NIF's performance in several areas NOT reached by the other early-NIF campaigns

[Hot Hohlraum slides courtesy of Marilyn Schneider]

The 5 NEL Hot Hohlraum shots were truly a team effort

Lead Theorist: **D.E. Hinkel** *(invited talk at APS DPP**)*

Lead Experimentalist: **M.B. Schneider**
Co-Leads at NIF: B.K. Young, J.P. Holder
Thanks to M.J. Eckart for guidance and support

Theory Team (A/X Division):
D.E. Hinkel, A.B. Langdon (leaders)
L.J. Suter, E.A. Williams, C.H. Still,
D.H. Munro, M.J. Edwards

Experimental Team :
M.B. Schneider, O.L. Landen, J.P. Holder, B.K. Young,
D. Bower, K.M. Campbell, J.R. Celeste, S. Compton, R. Costa,
E.L. Dewald, D.C. Eder, A. Ellis, J.A. Emig, J.M. Foster,
D.H. Froula, S.H. Glenzer, R. Griffith, D. Hargrove, G. Holtmeier,
D.H. Kalantar, R.L. Kauffman, J. Kimbrough, R.K. Kirkwood,
A.E. Koniges, D.L. James, G. Jones, J. Kamperschroer, M.R. Latta,
A.P. Lee, F.D. Lee, M. Landon, B.J. MacGowan, A.J. Mackinnon,
K. Manes, T. McCarville, J.W. McDonald, C. Niemann, D. Pellinen,
K. Piston, G.D. Power, I. Reinbachs, V. Rekow, M.A. Rhodes,
J. Schein, M.S. Singh, G. Slark, R.E. Turner, P.A. Waide,
A. Warrick, P. Watts, F.A. Weber, P.E. Young,
H.A. Baldis, M.J. Eckart, R.F. Heeter, M.J. May,
R. Shepherd, P.T. Springer

Laser Science Team:
S.N. Dixit, J.R. Murray,
C. Haynam, K. Jancaitis
BLIP group

Target Fab:
R. J. Wallace
J. Ruppe

PLUS
E. Moses
and NIF Program

Funding for smoothing/diagnostics
C.P. Verdon (AX Division Leader)

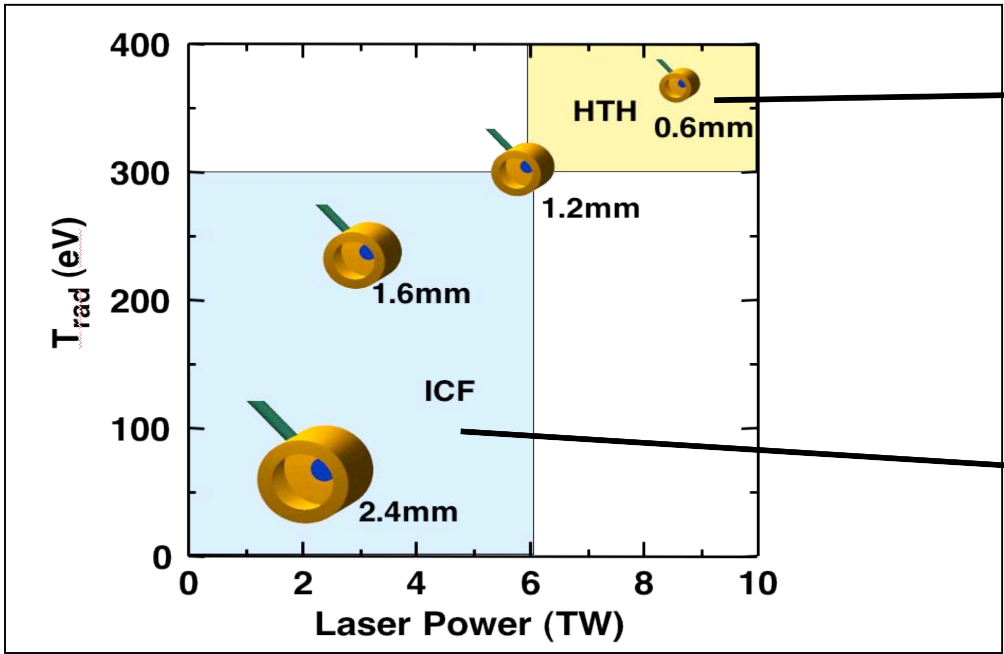
HTH was honored to be part of this great team at NIF

***D.E. Hinkel et al, Phys. Plasmas (May,2005)*

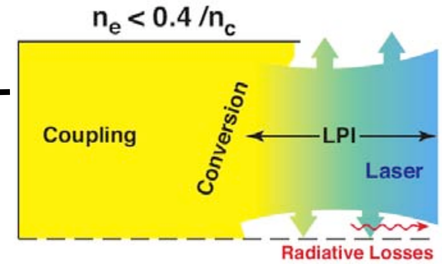
Hot Hohlraums seek to extend hohlraum radiation performance to higher radiation temperatures (T_{rad})

How to get hotter? • small targets • high intensity • short times

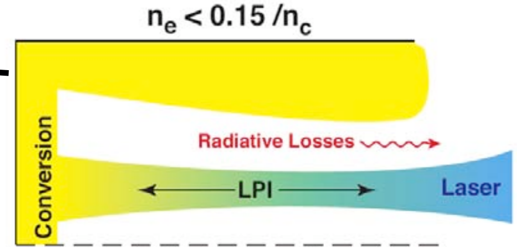
HTH targets are smaller, use higher laser power, and could reach T_{rad} > 300eV at NEL



HTH: Laser-plasma interactions occur at or outside the target



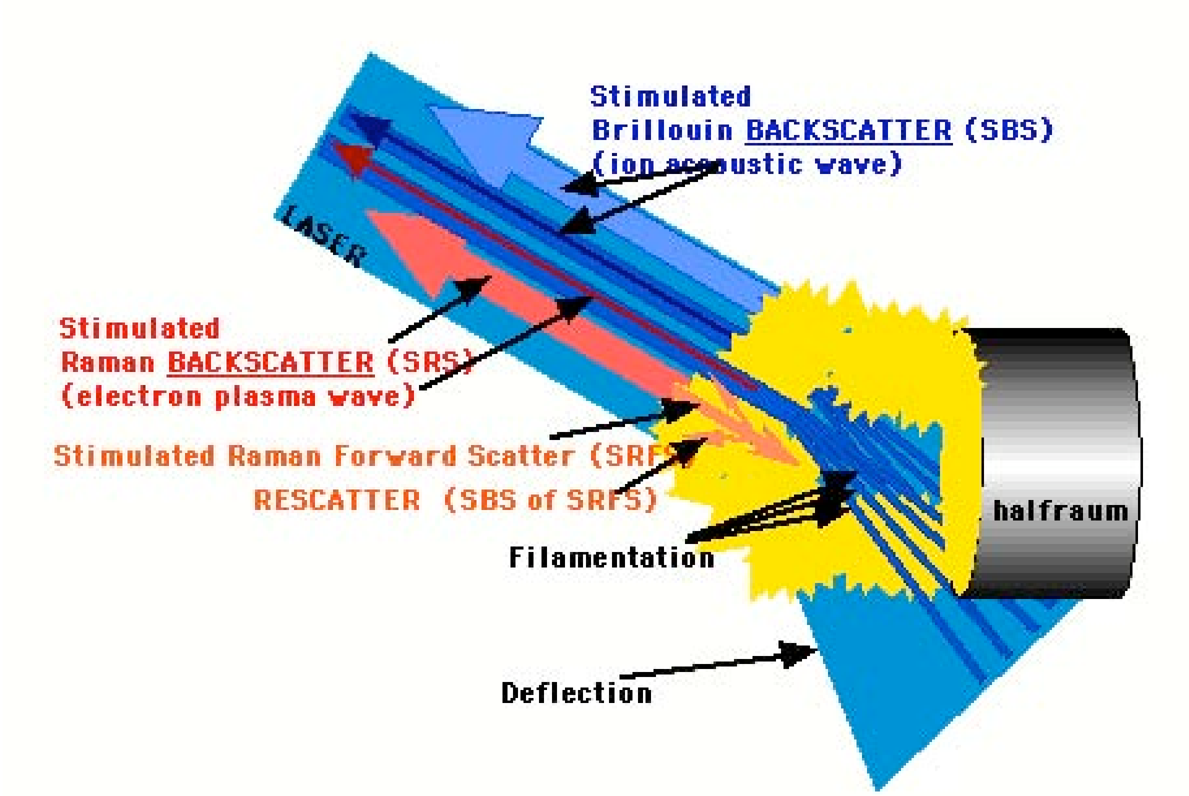
ICF: Laser-plasma interactions occur inside the target



The Hot Hohlraum shots extended the physics regime achievable at NIF Early Light (NEL) ***[into territory relevant for NIF opacity]***

At the higher intensities typical in HTH experiments, Laser-plasma interactions can limit laser/hohlraum coupling

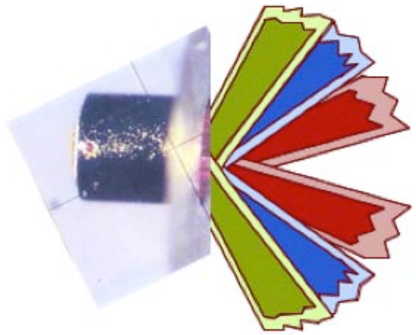
Plasma filling and angled, non-ideal beams result in complex laser-plasma interactions



A simple experimental geometry helps one test these complex models

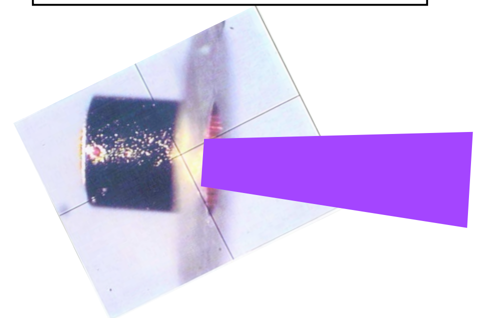
NEL geometry is simpler than OMEGA

OMEGA setup



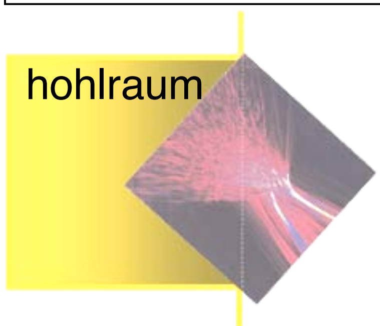
- 19 beams
- oblique angles

NIF setup



- 1 quad of beams
- normal incidence

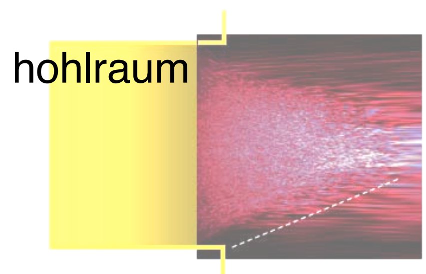
PF3D simulation



D.E. Hinkel (A/X Div)

- filamentation
- deflection
- cross-beam energy transfer

PF3D simulation



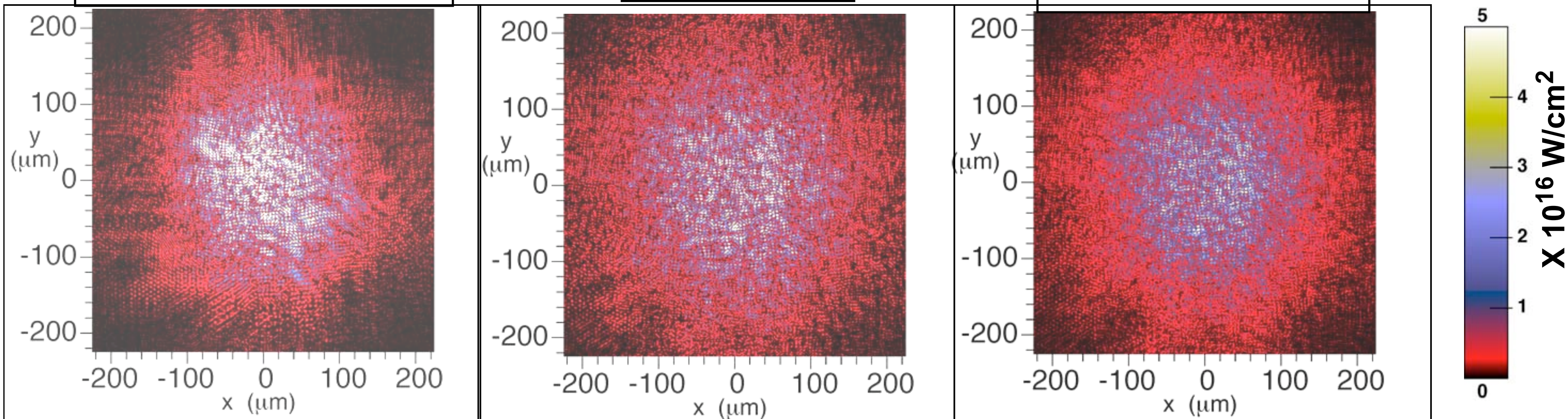
D.E. Hinkel (A/X Div)

- filamentation

Laser-hohlraum coupling at NIF was expected to be better than at OMEGA

The NEL laser beams were conditioned with both spatial and polarization smoothing

Unsmoothed Beam | CPP Beam | CPP + PS Beam



Unsmoothed Beam
- 80% laser energy in 320um diameter spot
- 10% power above 6.9×10^{16} W/cm^2

CPP Beam
- 80% laser energy in 370um diameter spot
- 10% power above 3.8×10^{16} W/cm^2

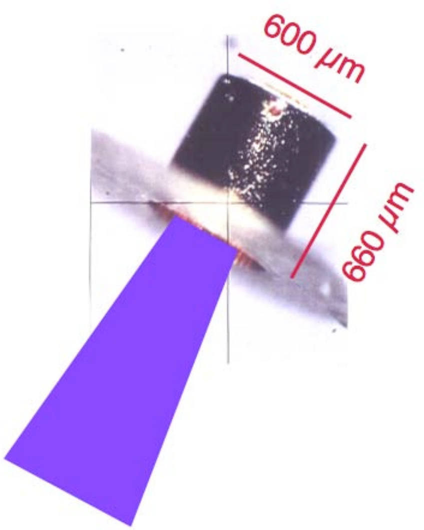
CPP + PS Beam
- 80% laser energy in 400um diameter spot
- 10% power above 2.65×10^{16} W/cm^2

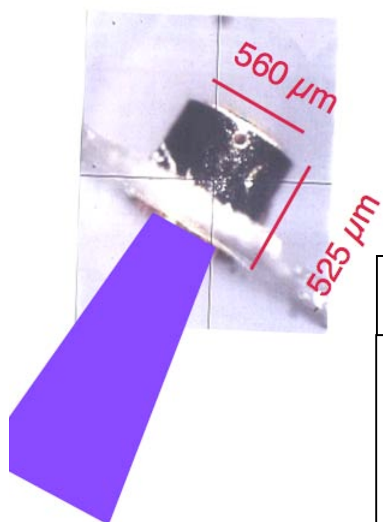
V Division and ICF shared PS crystal costs; HTH group led effort to get PS crystals fielded

NEL beam simulations, CPP design: S. N. Dixit, K. Jancaitis   PS crystal design: D. H. Munro, S. N. Dixit, A. B. Langdon, J. R. Murray

HTH experimental conditions and shot matrix

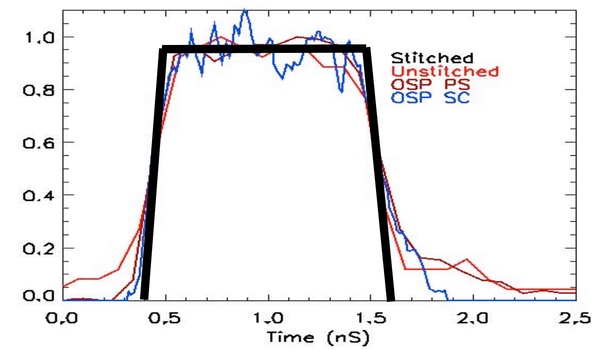
Targets were halfraums with different aspect ratios





• 3.5μm Au walls

Pulse shape was flattop, 1.1nS FWHM

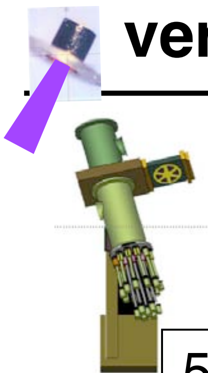


The 5 HTH shots at NIF

Target	Energy	Smoothing
560um	6 kJ	CPP+ PS
560um	9.5kJ	CPP+ PS
600um	9.5kJ	CPP+ PS
560um	9.5kJ	CPP
600um	9.5kJ	CPP

Good data was obtained on every shot

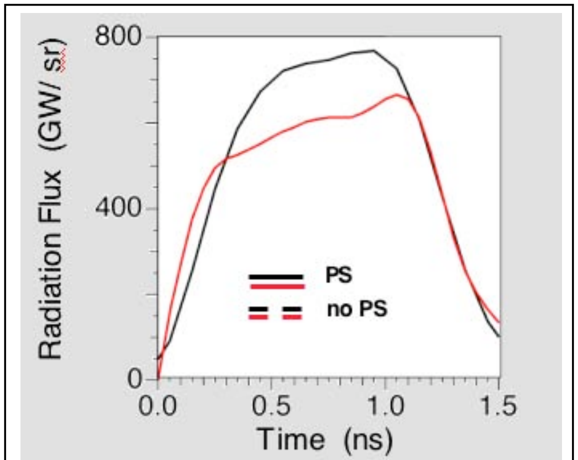
The measured radiation flux showed very good coupling



21.8°

DANTE: absolutely calibrated x-ray spectrometer
•Eighteen-channels •Mirror+filter / XRD •Filter /XRD
• All elements pre-calibrated to 5keV •Filters checked after EVERY shot
ICF: K.M. Campbell, J. Schein, O.L. Landen, R.E. Turner, E.L.Dewald; M Div: F.A. Weber

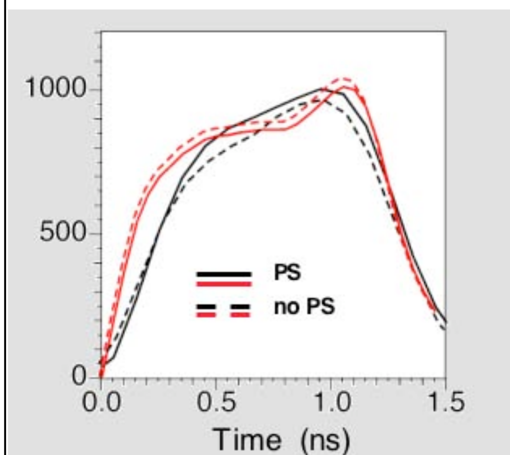
560 um 6kJ



— PS Exp: T_{rad} ~318 eV
— Lasnex: T_{rad} ~307 eV

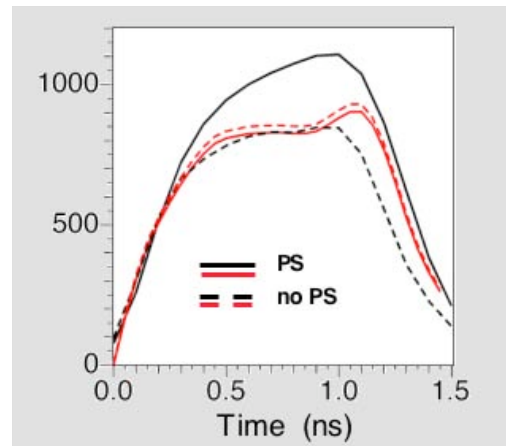
LASNEX: D.E. Hinkel (A/X Div)

560 um 9.5kJ



— PS Exp: T_{rad} ~340 eV
— Lasnex: T_{rad} ~337 eV
- - - No PS Exp: T_{rad} ~340 eV
- - - Lasnex: T_{rad} ~343 eV

600 um 9.5kJ

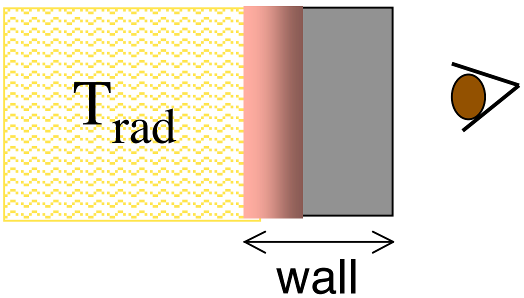


— PS Exp: T_{rad} ~337 eV
— Lasnex: T_{rad} ~320 eV
- - - No PS Exp: T_{rad} ~315 eV
- - - Lasnex: T_{rad} ~322 eV

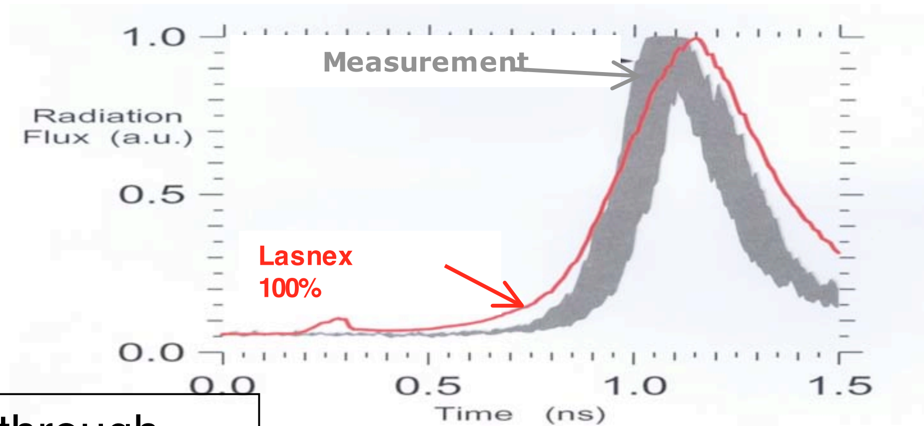
Coupling is better than predicted by LASNEX and is improved with PS

The Hot Hohlraum campaign implemented a second method of measuring radiation drive

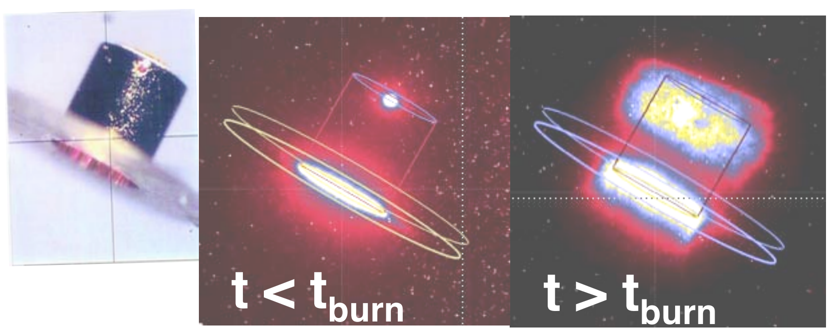
Intense radiation flux inside hohlraum heats wall



Radiation flux from outside wall increases when it gets hot

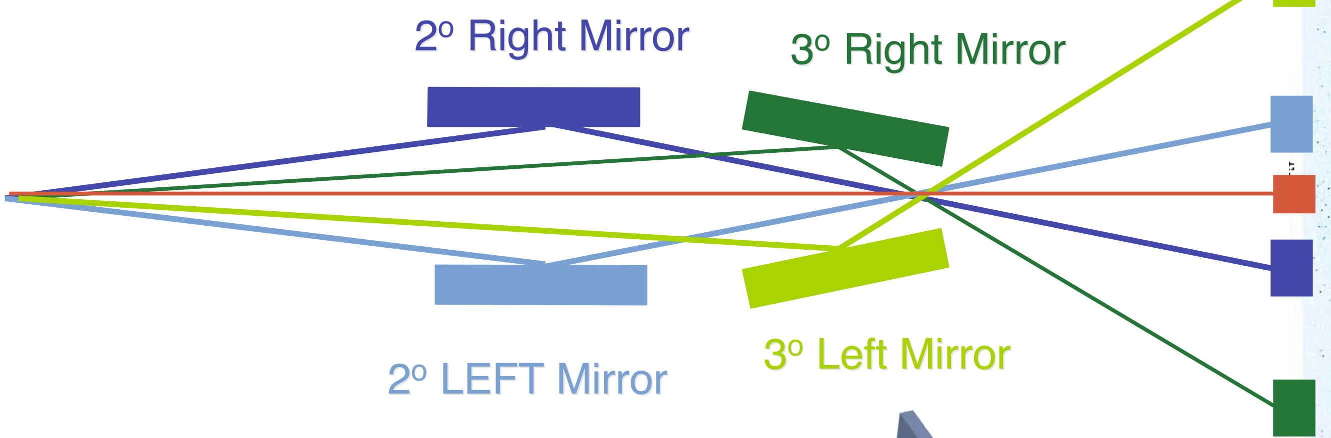


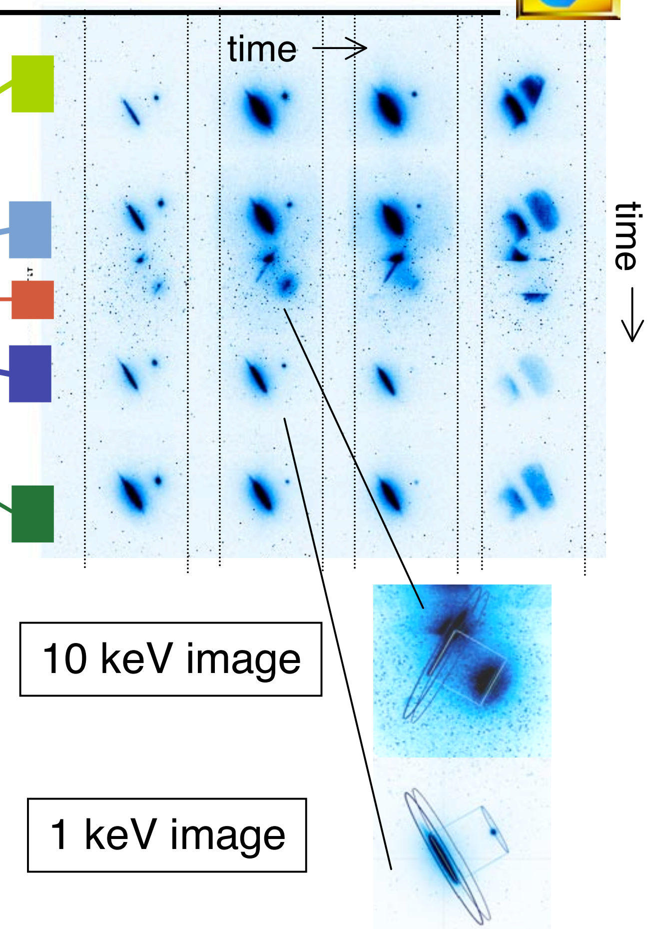
Soft x-ray images show x-ray burnthrough

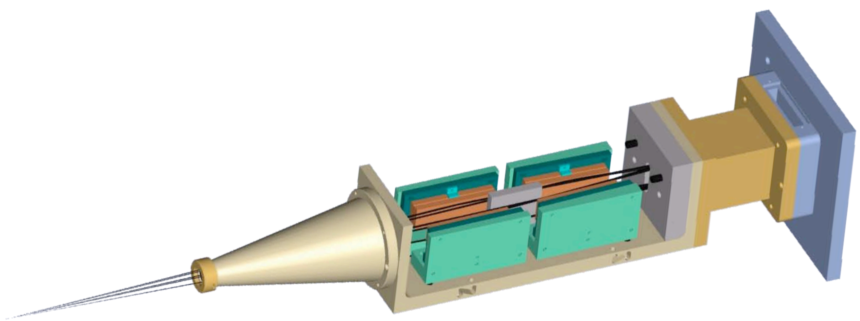


The x-ray burnthrough diagnostic measures the internal radiation field

The x-ray burnthrough diagnostic (built by V Division) was the SXRI snout mounted on the FXI framing camera





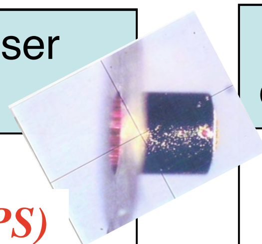


FXI: J.P. Holder (V Div), V. Rekow (ICF) SXRI: M.B. Schneider, D.L. James, J.P. Holder, J.A. Emig, H.C. Bruns, J. Celeste, G.D. Powers, B.K. Young, Filters: A. Ellis (V Div), J. McKenney, O. Garcia (SNL)

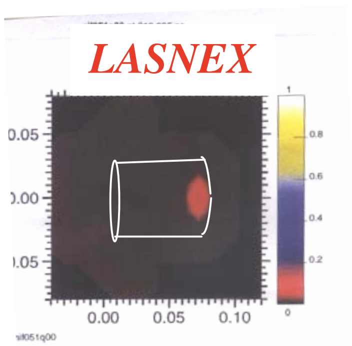
This instrument produced 16 soft x-ray images at 50pS intervals, and 4 hard x-ray images

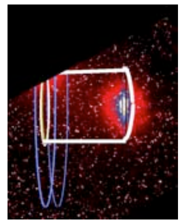
Hard x-ray images show laser deposition region and soft x-ray images show x-ray burnthrough

Early in time, images at 10 keV show laser deposition region is at back of can.



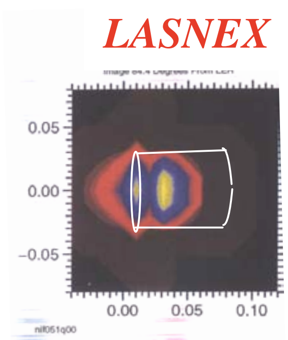
LASNEX | ~75pS | *DATA (with PS)*





Late in time, 10keV images do not see LASNEX prediction of deposition region near can front.

LASNEX | ~775pS | *DATA (with PS)*

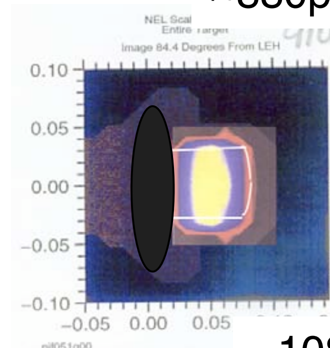


LASNEX: D.E. Hinkel (A/X Div)

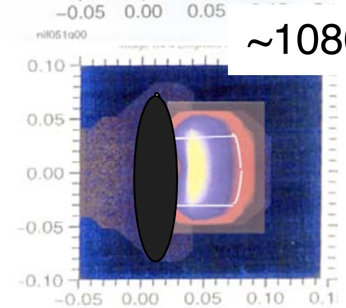
1keV images: burnthough starts at back of can, but LASNEX predicts in the middle.

LASNEX | *DATA (with PS)*

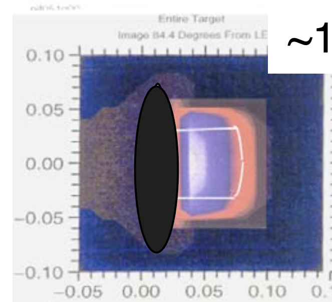
~880pS

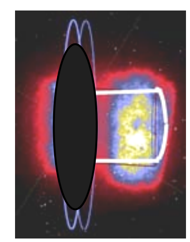


~1080pS



~1280pS

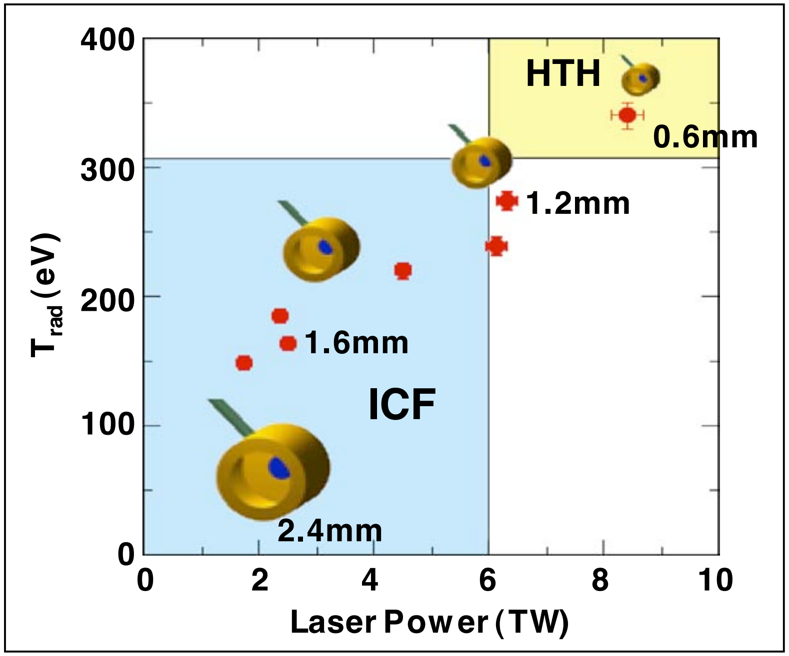




These experiments showed slower hohlraum filling than LASNEX predicts

All five hot hohlraum shots at NIF showed excellent laser coupling to target (T_{rad} > 300eV)

HTH shots DID extend NEL physics regime



Hot hohlraums coupled best (better than expected)

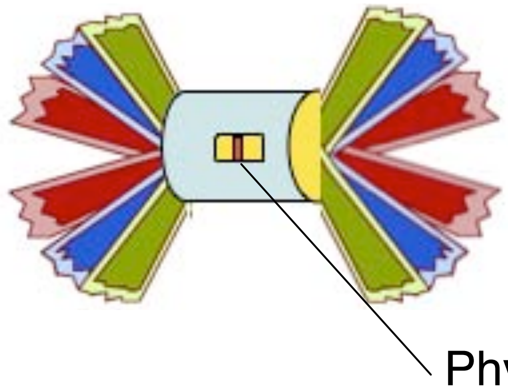
- with smoothed beams
- less extreme conditions
  - larger hohlraum at full energy
  - smaller hohlraum at reduced energy

HOHLRAUMS did not fill with plasma as fast as expected, thus reaching the higher radiation temperature -- not sure why, many ideas…

Other results (backscatter, hard x-rays) give some insight, more physics (not discussed here)

The NIF Hot Hohlraum campaign opens the door for performing hot radiation experiments on real targets

Future: Use High Temperature Hohlraums as x-ray drivers for real experiments . . . *at OMEGA laser*



LDRD (PAT-ER):

Development of Hot, LTE-tunable Radiation Sources Enabling:
Material Science Studies
and
Radiation Transport Simulations in Astrophysical Plasmas

Co-Investigators:
Hector Baldis (UC Davis, V Division)
Duane Liedahl (V Division)
Klaus Widmann (V Division)
Stephanie Hansen (V Division)
Carmen Constantin (UC Davis post-doc)
Steven Ross (UC Davis Ph.D. Student)

Collaborators:
Denise Hinkel (A/X Division)
Peter Beiersdorfer (V Division)
Hyun-Kyung Chung (V Division)
Mark May (V Division)
Bruce Young (V Division)

These experiments add physics to existing OMEGA NLUF shots in collaboration with Hector Baldis

Omega Opacity experiments required development of multiple gated imaging spectrometers

Status Quo 2 years ago:

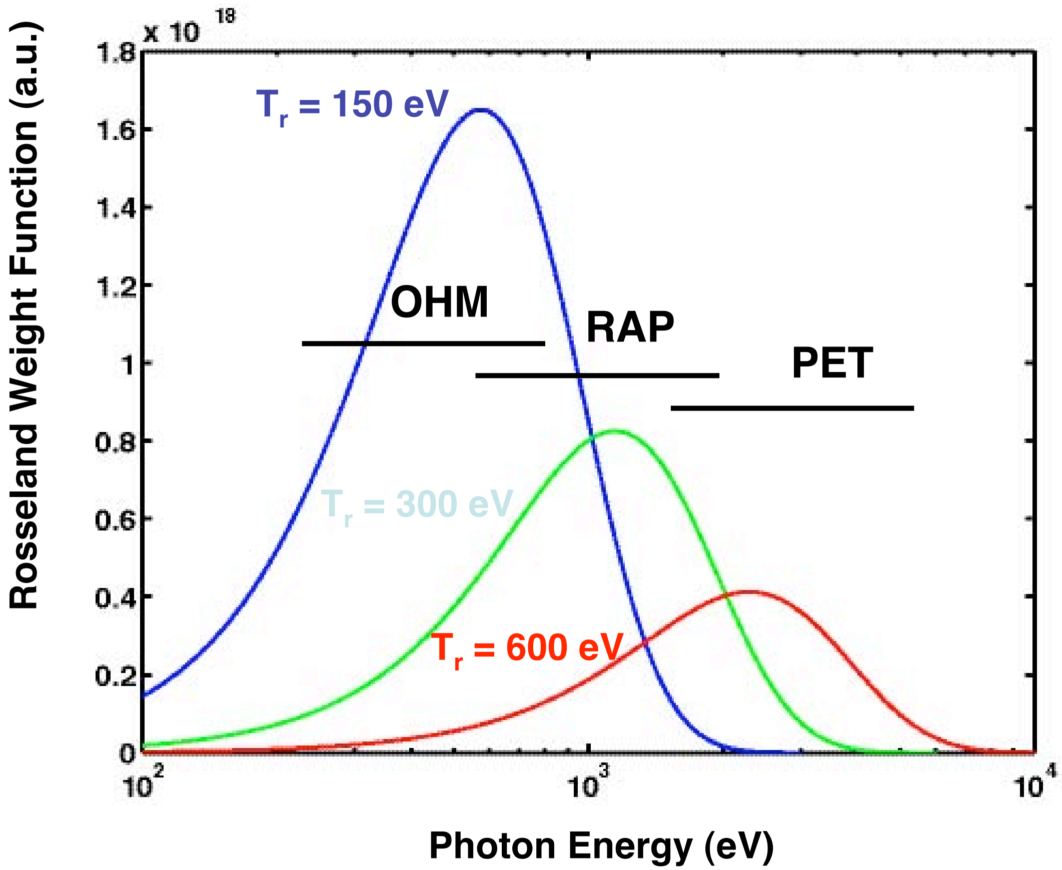
Omega had >5 general-use framing cameras, but only one spectrometer of value for opacity (the old Nova TSPEC, which we'd ported for Non-LTE Au experiments. But TSPEC clips beams.)

New Multipurpose Spectrometer snout (MSPEC)

- **1st unit deployed June 2003**
- **Goes on XRFC/FXI-class 4-strip (6x34 mm) cameras**
- **Non-interfering in any laser/target configuration so far**
- **Now have 4 interchangeable units; all have been deployed**
- **4 crystal configurations in use at present**
  - **Convex (2.0-4.5 keV with RAP)**
    (M. May et al., RSI 75, 3740 (2004))
  - **Elliptical (1.0-1.9 keV with RAP; also PET, OHM)**
    (R.F. Heeter et al., RSI 75, 3762 (2004))
  - **2 different Flats (RAP 1.5-1.85 keV; PET 3.9-4.6 keV)**

MSPEC-Elliptical provided technical foundation for the new "OZSPEC"

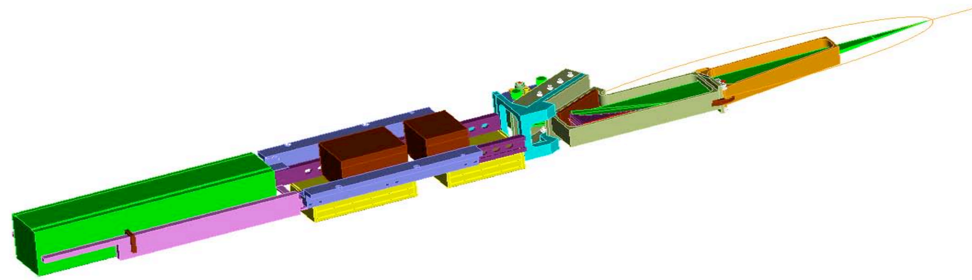
Rosseland Mean Opacity experiments at the higher temperatures anticipated on NIF require new instrumentation



- Need broad spectral coverage
  250 eV to > 5000 eV
- Desire resolution $E/\Delta E > 500$
- Crystals scale to higher Tr; gratings do not
- New-ish OHM crystal
  - 63.5Å 2d, $E/\Delta E$ ~1000
  - opens up soft X-ray range down to 240 eV
  - can be bent to 25 mm radius
- Broadband and high resolution: need many pixels: Zipper

A broadband, high-resolution crystal spectrometer would enable validation of opacity codes in regimes of highest impact.

Opacity Zipper SPECtrometer (OZSPEC) design satisfies requirements and makes advances in key capabilities



- "Zipper" detector + elliptical crystal spectrometer = OZSPEC
  - 200 ps gated large format multi-channelplate (MCP) detector
  - Broad spectral range and high resolving power; 2.5x better than previous spectrometers
  - high spatial resolution; required for 800 μm diameter hot hohlraum opacity experiments
  - Compatible with Omega TIM carts
- Diagnostic is development of B. Young's concept (JOWOG-37 Jan. 2002); motivated by HED experimental requirements

Design results in 2-3 times more data in 200 ps than other framing camera instruments

OZSPEC development was a team effort

- Instrument is work of many:
  S. Anderson, R. Heeter, B. Young, T. McCarville, J. Emig, R. Booth, M. Schneider, D. Norman, I. Reinbachs, L. James
- Immediate application is opacity measurement/code validation at LLE
  – Difficult measurement; requires spatial /spectral /temporal resolution, precision calibration, etc.
- Stepping stone to NIF diagnostics
- Supported by $1.1M from AX-division (Feb. 2004 - Nov. 2004)
  – PDRP added ~$300k to finish prototype instrument

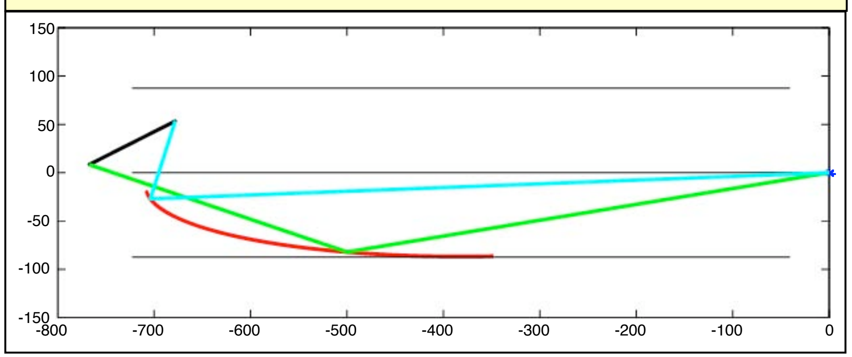
Spectrometer design achieves broad bandwidth and high resolution

- **Uses OHM, RAP, PET (2d = 63.5, 26.1, 8.7 Å) xtals with Bragg angle to overlap spectral coverage (14-55°)**
  - **OHM: 238-807 eV, RAP: 579-1962 eV, PET: 1729-5862 eV**

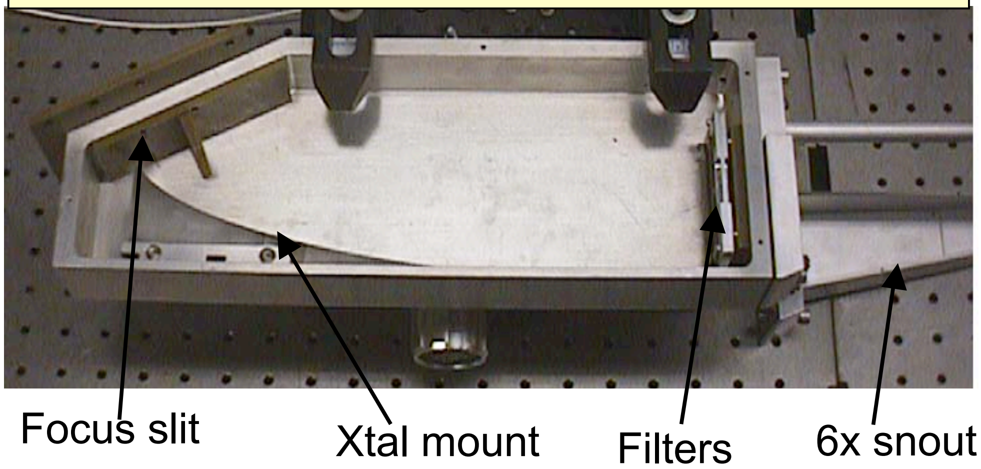
- **Ray tracing design optimized resolution/sensitivity given TIM space constraints**

- **Elliptical geometry allows shielding at second focus**

Ray-tracing design output



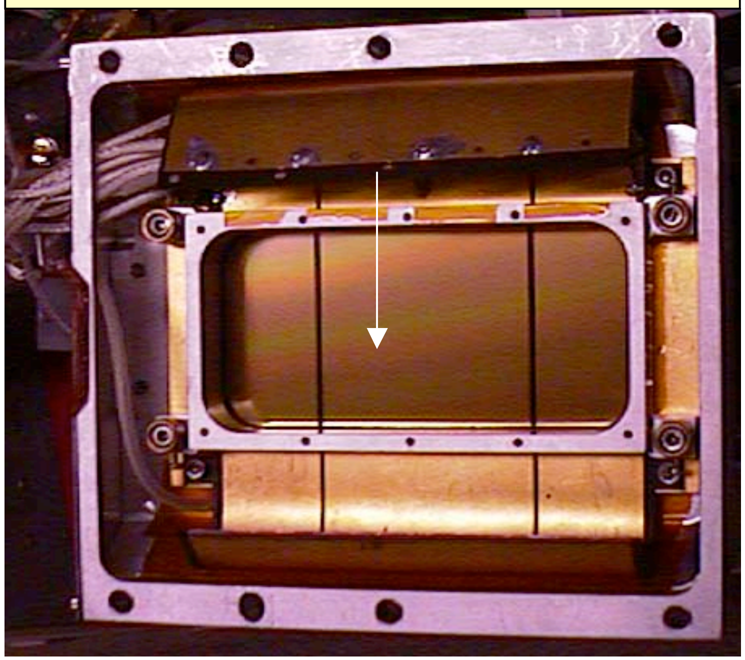
Fabricated spectrometer body

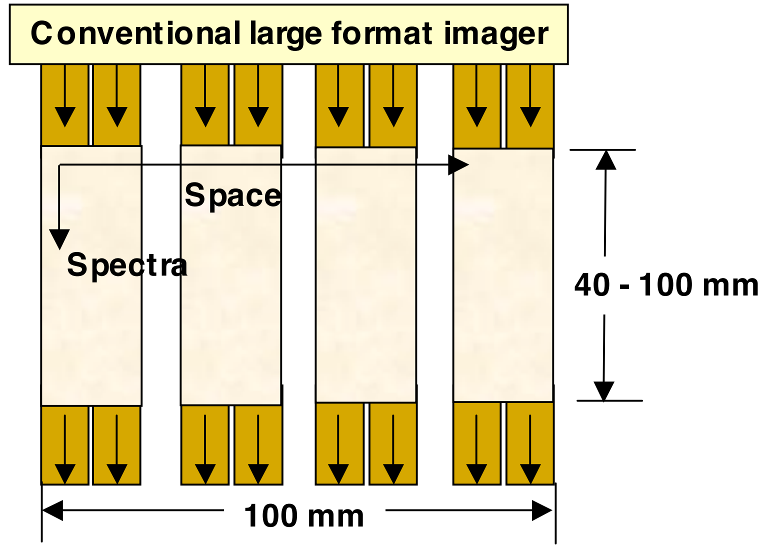


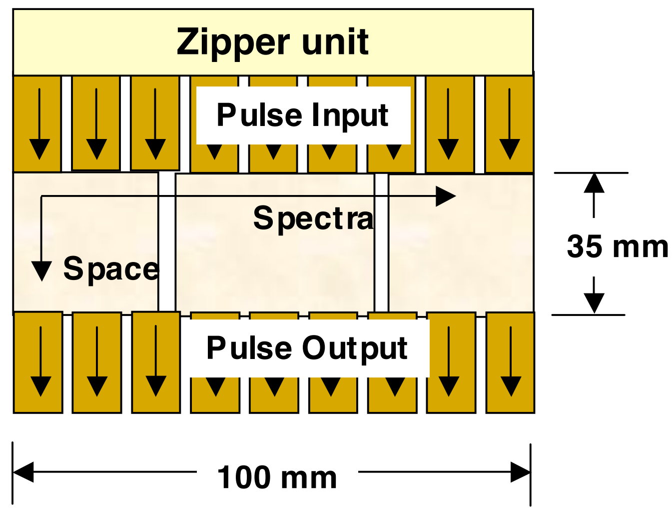
A new large-format, gated "Zipper" detector provides the required increase in image area

- Records spectra distributed over a large area within ~ 200 ps
- Uses same pulser & electronics as standard Nova / Omega framing cameras

MCP detector assembly



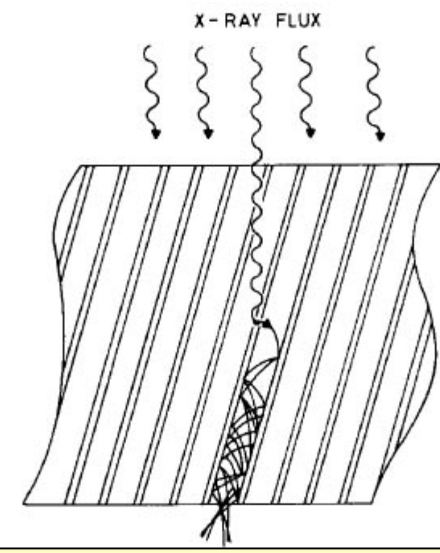




- Major development effort; paper by Tom McCarville et al. submitted to Rev. Sci. Inst.

Detector modeling is required for precision measurements

- **Experiments demand ~ few percent level calibration of instrument; opacity error bars, temperature determination.**
- **Need good models of component response**
  - **Film**
  - **Crystal reflectivity, dispersion**
  - **Filter attenuation**
  - *MCP response*
    Complicated function of incoming photon energy/angle, plate material, end spoiling, gain model, etc.



Schematic diagram of a microchannel plate*

*J.E. Bateman, *Nucl. Instrum. Methods*, **144**, 537 (1977).

We have coded a detailed MCP response model which agrees well with earlier experiments

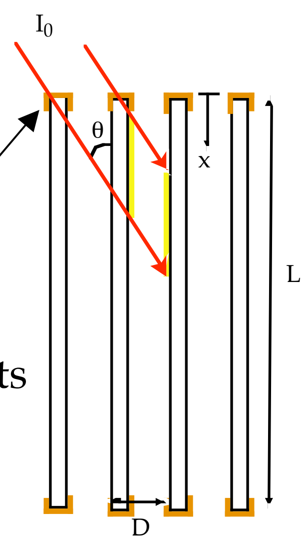
- **MCP model based on Landen paper:**

Landen, et al., Rev. Sci. Instrum., Vol. 72, pp. 709-712, (2001).

$$Q \quad S(E)\left[\frac{R(E)}{\mathrm{mfp}(E)\sin\theta}\right]\cos\theta \sum_{n}^{\#\,pores} \int_{pore} I_n(x) G_n(x)\,dx$$

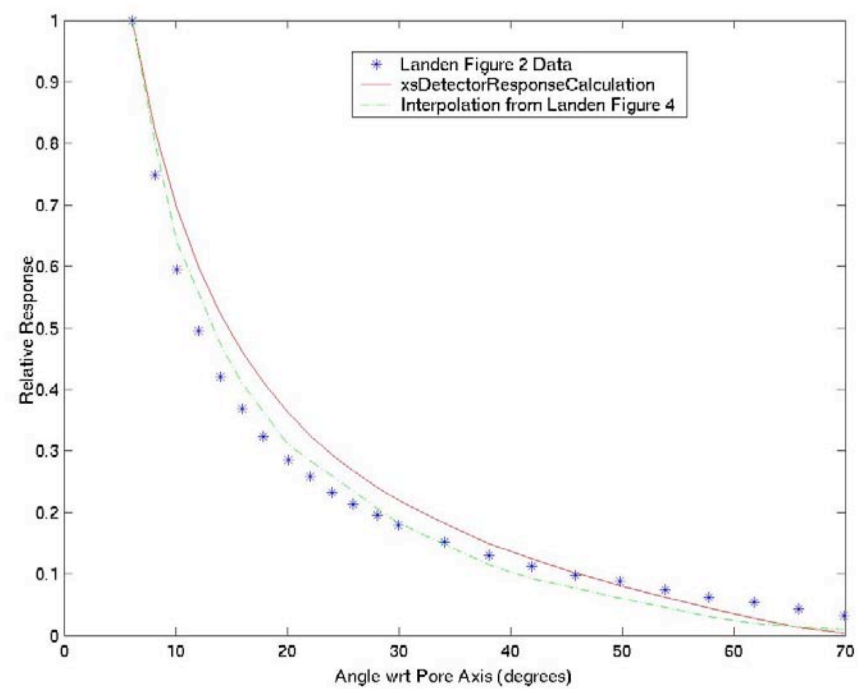
$$I_n(x) = I_0 \exp\left(-\frac{l_{atten}(\theta,n,x)}{\mathrm{mfp}(E)}\right)$$

$$G_n(x) = \left(\frac{V}{V_0}\right)^{\frac{L}{4D}\left(1-\frac{x}{L}\right)}$$



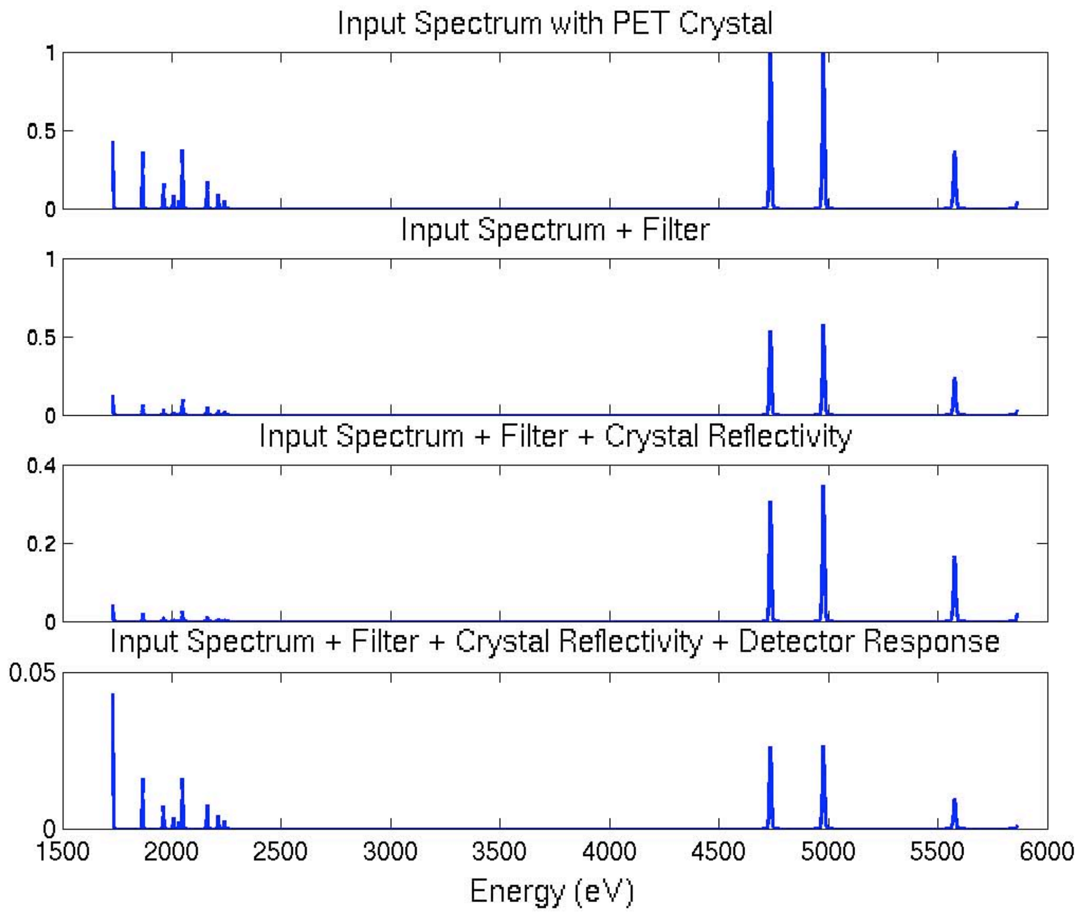
Includes end spoiling effects

Model and experimental MCP response versus X-ray incidence angle



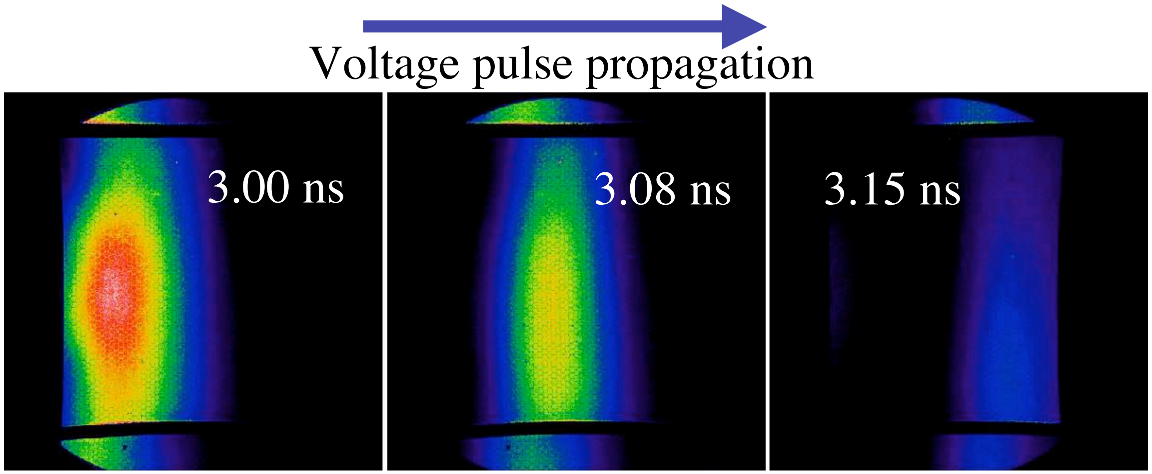
Full system model is used to balance intensities at ends of spectra

- Simulated response of the PET channel of the spectrometer.
- FAC generated K shell emission lines of H- and He-like Ti and Al (Alumina+Ti target for Janus shots)
- Cumulative effects of the filters, crystal reflectivity, and MCP response.

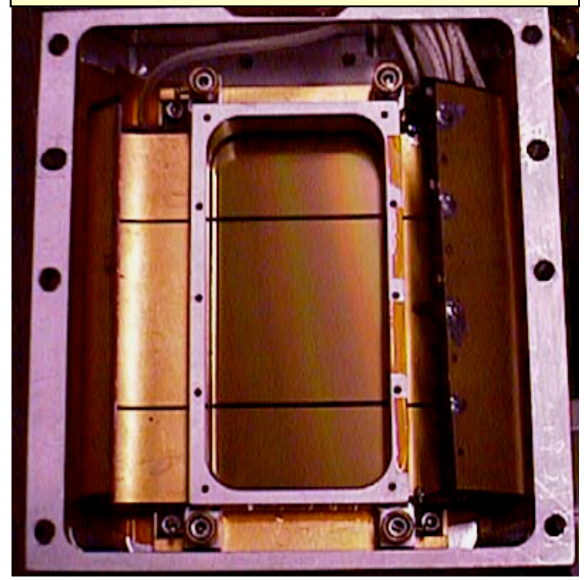


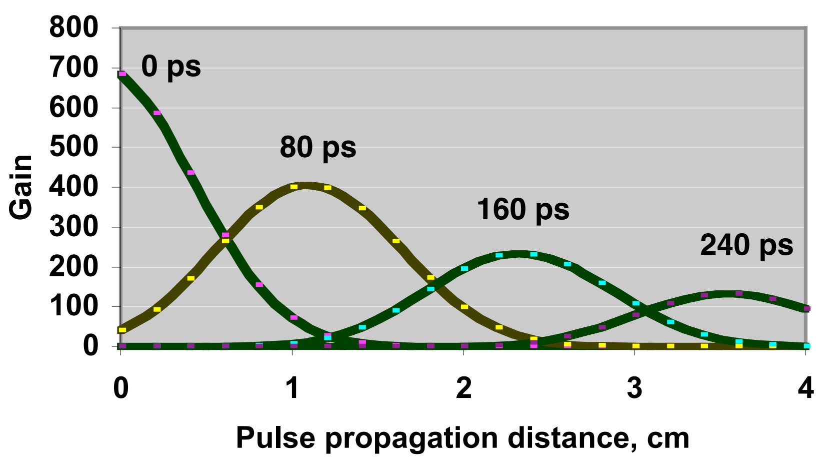
Instrument model facilitates immediate analysis and/or trouble-shooting of data during experiments

The Zipper was tested in gated mode using an ultra-short pulse laser in February



Zipper detector as installed





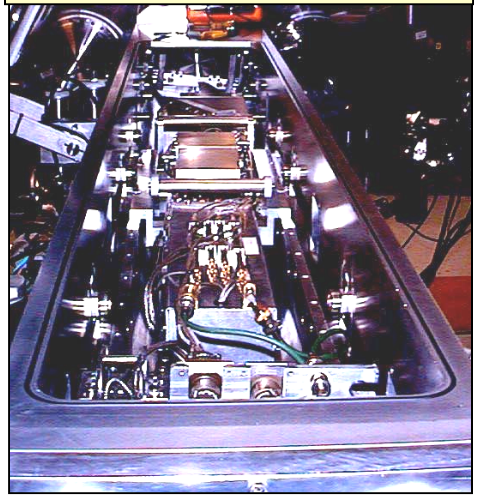
- DC and pulsed mode observed x-rays
- PCD and HV pulse monitor timing set
- USP x-rays allow direct measurement of gain pulse in MCP
- Usual factor of ~5 drop in gain across plate
- Optical gate FWHM < 100 ps

Zipper pulsed response is comparable to conventional cameras in direction of pulse

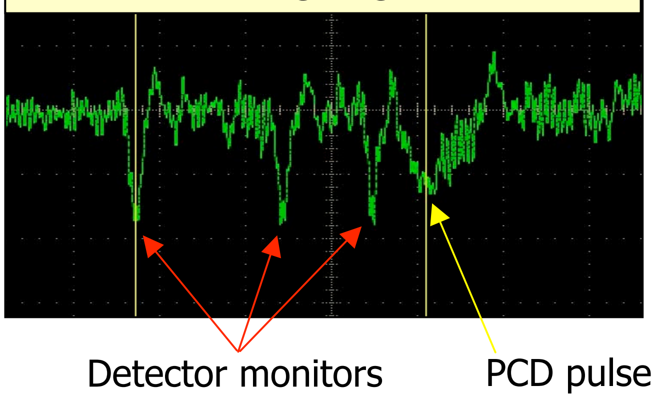
The full OZSPEC instrument was successfully tested at JANUS (180J in 1 or 3 ns) in March

- **Zipper + TMAX3200 film pack + elliptical spectrometer in an Omega-class TIM**
- **Gated spectra obtained on all 3 crystals (0.24-5.8 keV)**
- **Timing tuned in (for 1-3 ns laser pulses)**
- **Filter absorption edges and target line emission used to calibrate spectra**
- **Spatial resolution checked (60 μm slits)**
- **Channel-plate DC bias issues identified - prior to Omega shots**

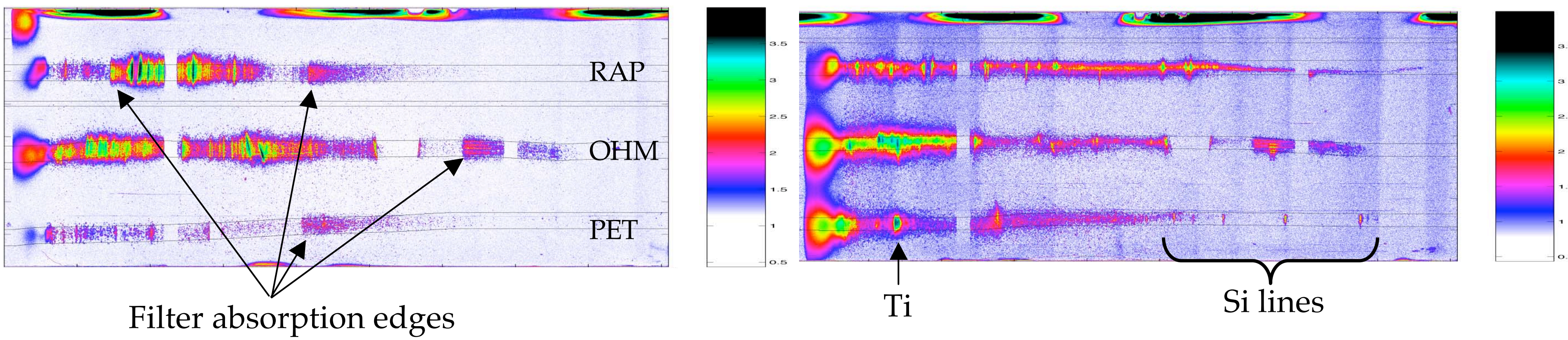
OZSPEC in TIM



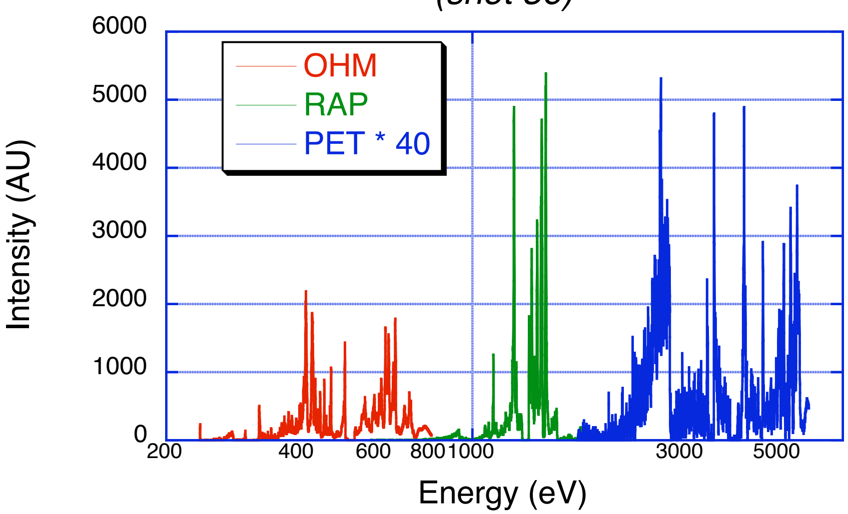
Timing Signals



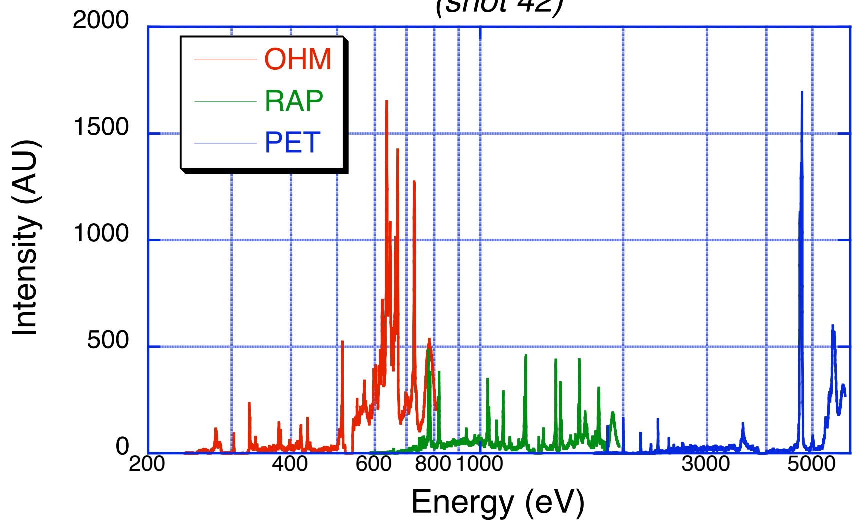
Gated spectra from JANUS runs provided a wealth of calibration data



Cu Spectrum
(shot 36)



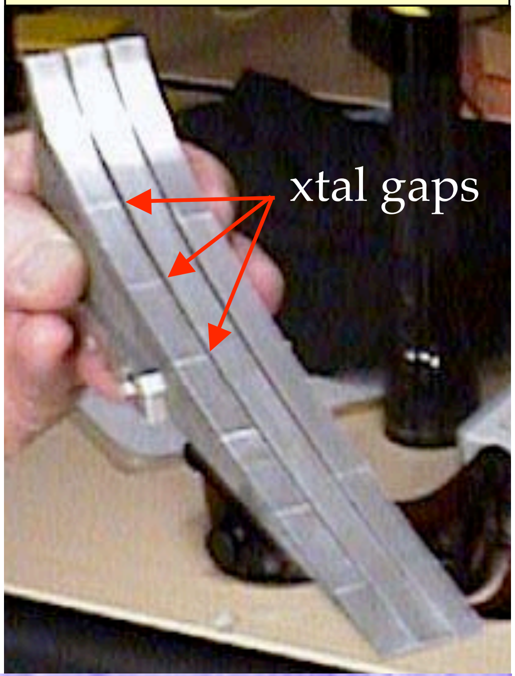
Pyrex + Titanium Spectrum
(shot 42)



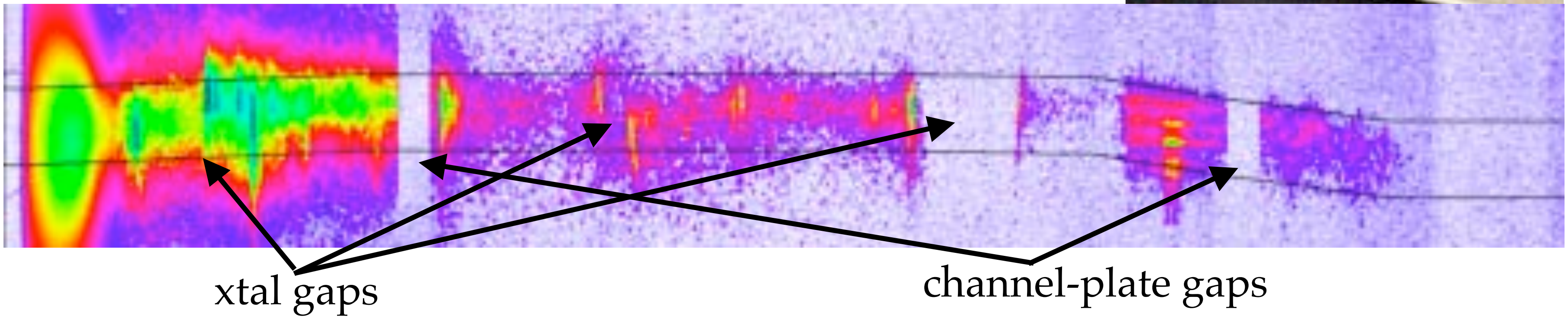
Early analysis has focused on quantifying and reducing the gaps in the spectral coverage

- Discontinuities in spectrum from:
  - 2 mm gaps between MCP strips
  - Edges of crystal pieces
- Use instrument model to align crystal gaps with MCP gaps
  - Done for Omega shots
  - Works well for RAP, PET;
  - OHM challenging (3 cm strips)
  - Mitigate: duplicate mounts with offset tiling

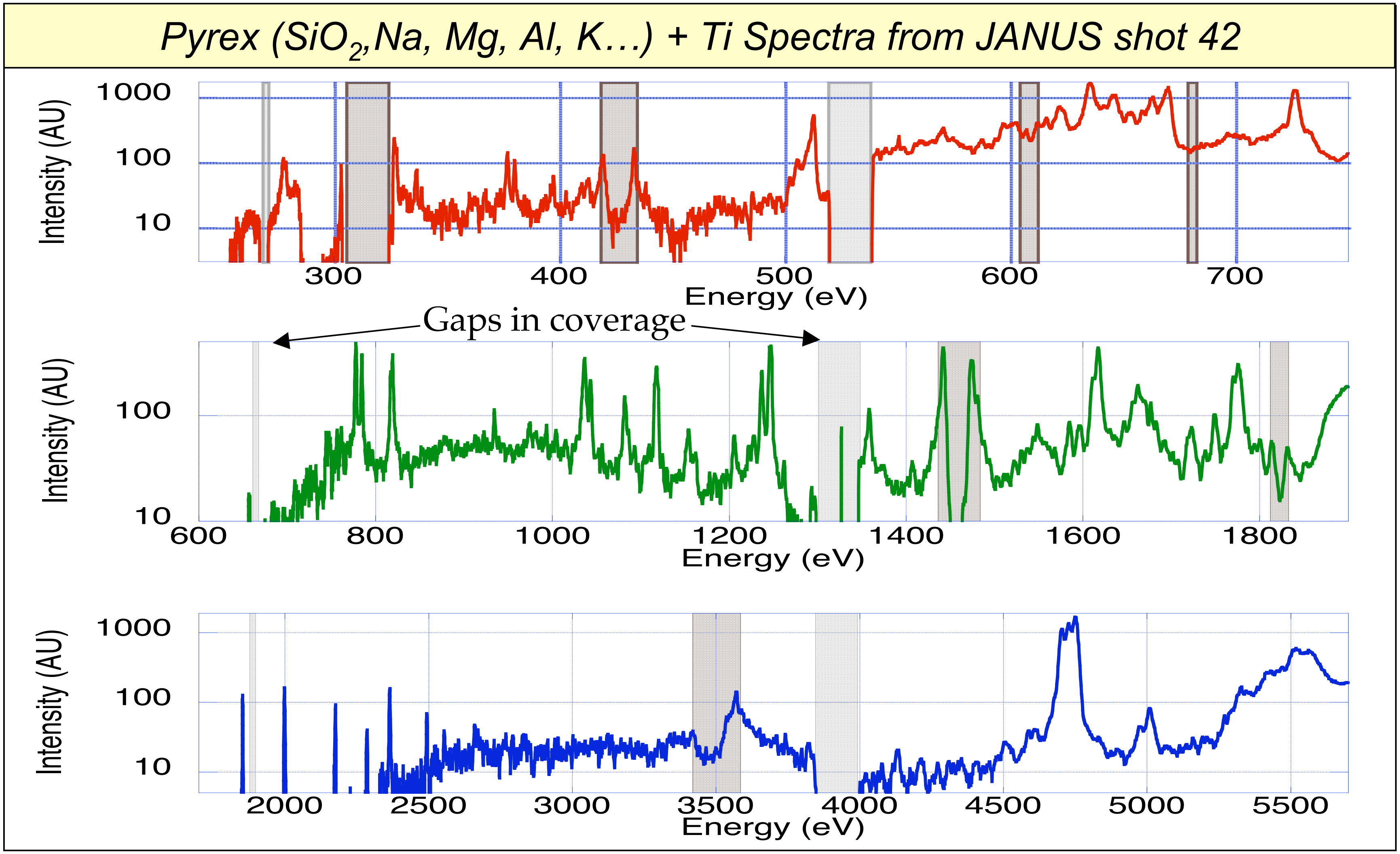
OZSPEC crystal mounts



OHM (240-800 eV) channel of Ti+pyrex spectrum



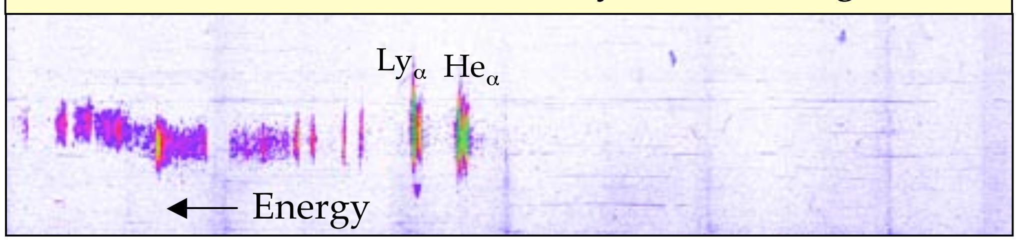
OZSPEC has the broad spectral coverage and high resolution ($E/\Delta E > 500$, crystal permitting) for which it was designed



OZSPEC was commissioned at Omega from April 4-8

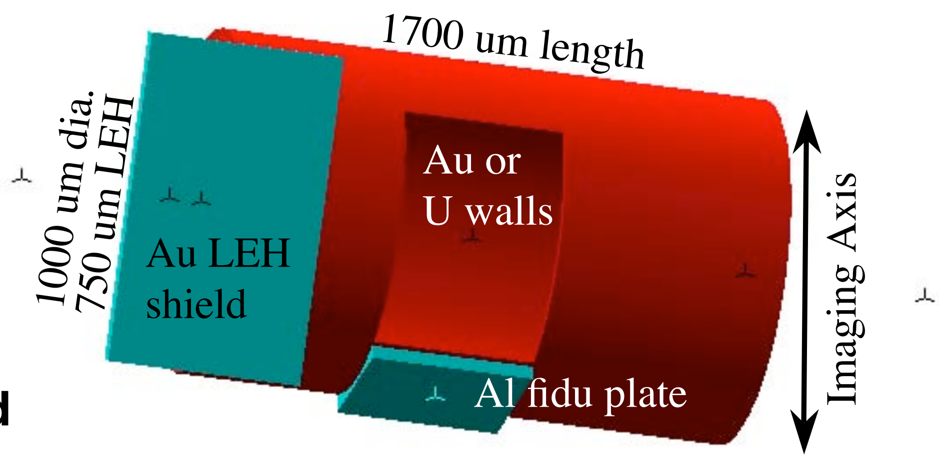
- JANUS and USP experience led to success at LLE
  - Had already resolved several issues that could not have been fixed on-the-fly at LLE: slit apertures, Zipper hardware, pulser supplies, negative biasing, etc.
- April 5-7: 24 “ride along” shots
  - Gated spectra acquired on very first shot; various targets viewed:
    - Polyimide ablators (C, N, O lines)
    - Hohlraum LEH M-bands (gold, cocktails)
    - Ti backlighter foils
    - Ag targets; Cl calibration shots
  - Timing tuned to ± 100 ps
  - OZSPEC data helping to resolve some unexpected mysteries

Chlorine lines on PET crystal at Omega



OZSPEC is now the workhorse instrument for LLNL's large-laser opacity experiments

- April 8: Backlighter Development
  - Primary Diagnostic
  - *7 shots (6 expected)*
  - *Excellent data from first shot*
  - OHM/RAP/PET: 250-5500 eV
  - Entire spectrum in each shot
  - Balanced signal levels
  - Film classified, was just scanned
  - Will show sample tomorrow

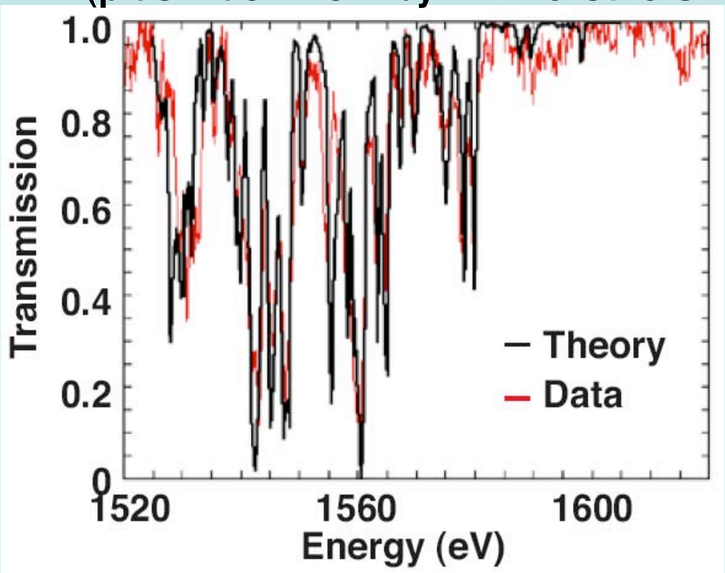


- June: OZSPEC to characterize point-projection "thermometer" backlight fibers (U, Sm…)
  - In conjunction with next Gd:Al (40 eV) experiments (talk tomorrow)
- Sept.: Possible 1st attempt at Rosseland Mean opacity measurement
  - Ta:Sc at > 100 eV in support of AGEX programs

UNCLASSIFIED

April shots: our other objective was to establish the n=1-to-2 point-projection absorption method at Omega

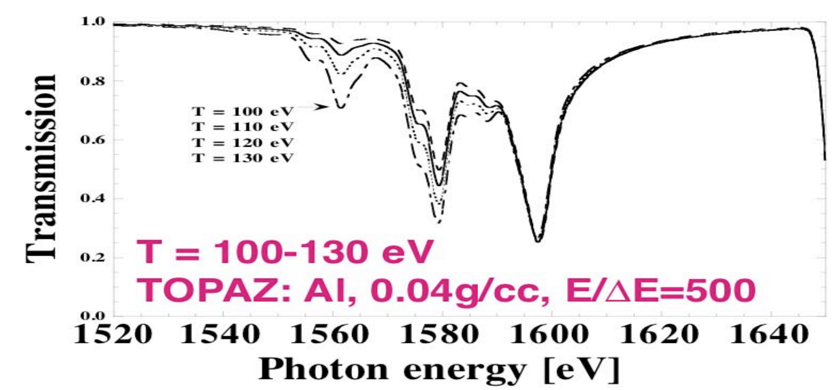
Perry *et al.* PRL 67, 3784 (1991)
(plus much work by AWE & others…)



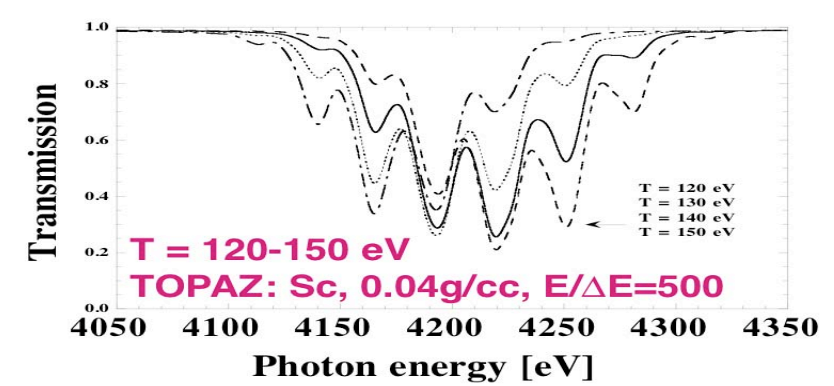
K-shell absorption features of L-shell ions are strongly temperature-dependent

We are indebted to Dave Hoarty and others at AWE for providing us their latest "recipes".

Extensions to Higher Tr (Carlos Iglesias)



Above 100 eV, Al has only a weak signature

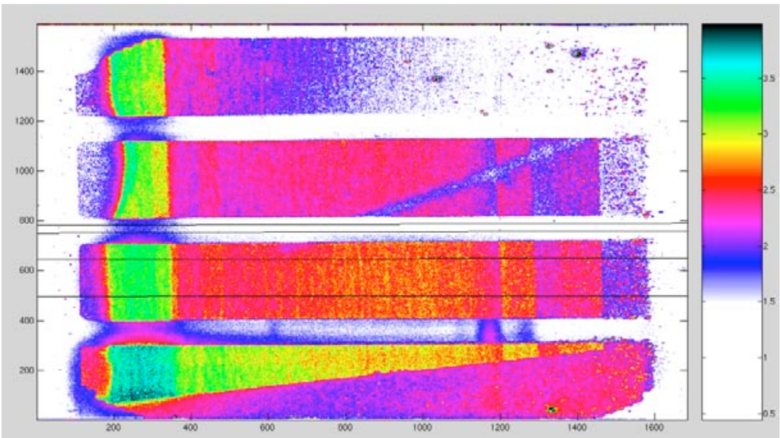


Higher-Z materials are possible (e.g. Sc)

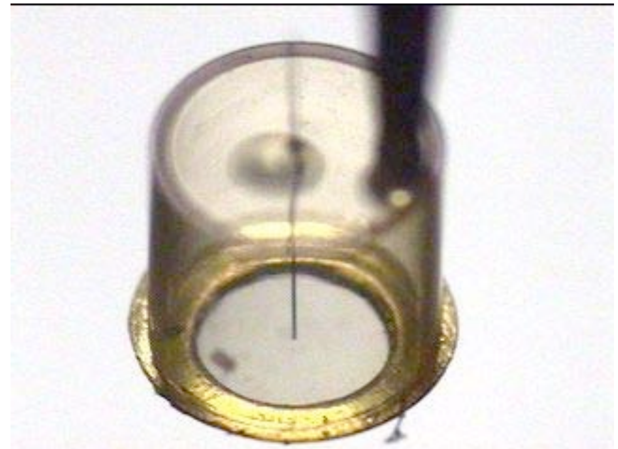
New point-projection backlight sources are needed for the higher-Z materials

We are beginning to digest the point-projection data for both the Al and Sc 1-2 spectral bands

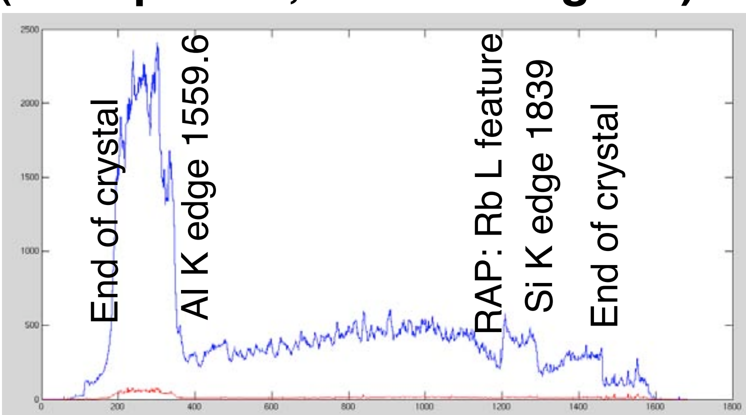
Image for flat RAP spectrometer, Sm fiber backlighter



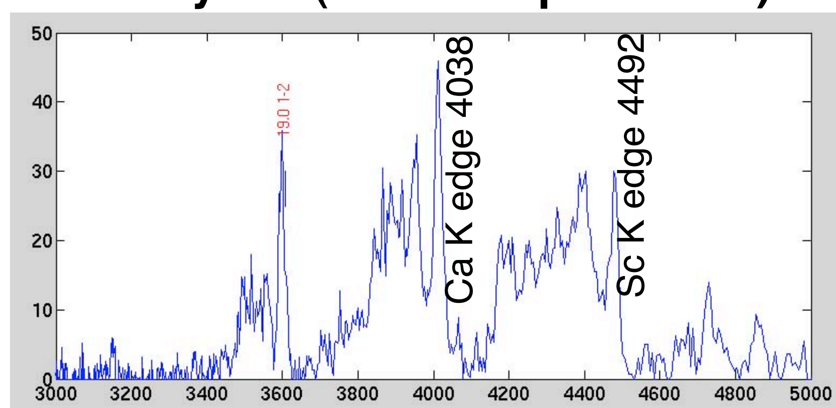
Fiber; epoxy can; Au washer



Lineout: Sm fiber, flat RAP crystal (as expected, nice backlighter)



Spectrum: Indium-Tin fiber, elliptical PET crystal (flat PET: poor data)



Need more work on this one…

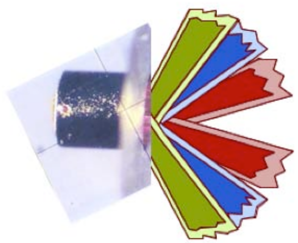
LLNL's revitalized opacity effort is delivering both near-term V&V data and capabilities needed for NIF

Experiment	Capabilities Required	Status
FY04	40 eV hohlraum design simulations	
Gd:Al	Tamped Samples Design & Fabricate	
1.1-1.7 keV	Gated Imaging Spectrometer	
"Rosseland Style"	Bright Uniform Area Backlighter (U/CH foil)	Limiting factor
	Data was acquired May & August 2004	
FY05	Point-projection spectrometer Al 1-2 range	Minor tuning needed
Gd:Al, Ge:Al	Sm fiber backlighter Al 1-2 range	Looks reasonable
1.1-1.7 keV	Point-projection spectrometer Gd-Al range	MSPEC-Ellipse point-proj.
"Perry Style"	U fiber backlighter Gd-Al range	Must check below 1.5 keV
ASAP	>100 eV hohlraum design simulations	
Ta for AGEX	Tamped sample design & fabrication	demo unit in fab
Rosseland Mean	Opacity Zipper Spectrometer	flat-field needed…
	Bright backlighter over Rosseland band	
	Point-projection spectrometer for Tr	demonstrated already
	Fiber backlighter for Tr measurement	needs more development
Future	Hot hohlraum design based on HTH shots	LDRD in progress
Omega Max Tr	Many more items…	
FY11+	Understand NIF beam coupling for HTH	NEL shots promising!
NIF High Tr	Many more items…	

Blue: discussed in the unclassified presentation
Purple: discussed in the classified presentation

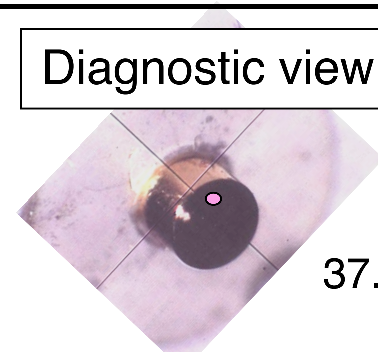
Backup Materials

OMEGA experiments show x-ray burnthrough and laser deposition region near FRONT of can



- 19 beams
- 9.5 kJ
- ~1nS flattop

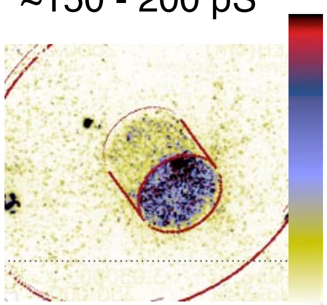
Diagnostic view of target



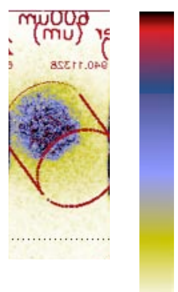
37.4º view of back wall

10 keV images see a laser deposition region move from back wall to front of can

~150 - 200 pS

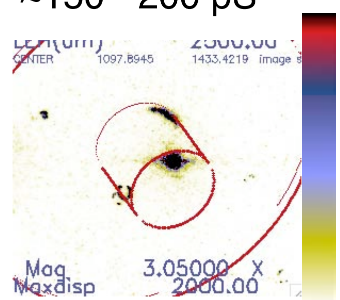


~600-650 pS

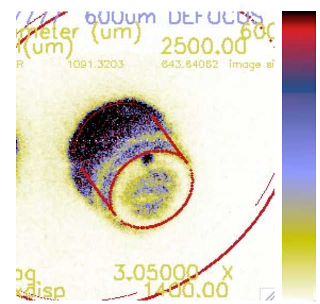


1 keV images see timing hole at early time and, at later times, burnthrough occuring first near front of can.

~150 - 200 pS



~600-650 pS



The OMEGA hohlraums filled faster and were cooler than the NIF hohlraums

Summary of HTH NIF experimental results

Results

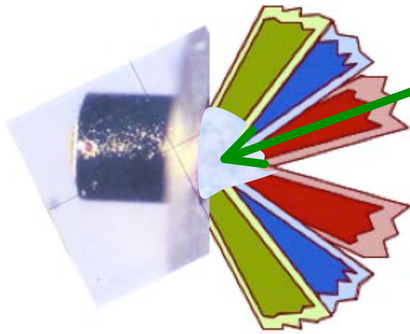
- Radiation temperature was measured showing very good laser coupling to target
- Backscatter: mostly Stimulated Brillouin outside lens
  - — filamentation causes beam spray
- Polarization smoothing
  - — enhances coupling
  - — affects Raman spectra
- Radiation drive higher than predicted
  - — images of x-ray burnthrough and hard x-ray region show laser deposition region moves to front of can at slower rate than predicted
- Linearly polarized drive beam produces 20% depolarized backscatter

  - — Exercised NIF diagnostics
  - — Extended NIF capability for AGEX

HTH success is due to an excellent collaboration between multiple groups: V Division , A/X Division, NIF Facility, ICF Program, NIF Diagnostics Group, AWE, A Program, M Division, UC Davis . . .

NLUF collaboration led by H. Baldis measures plasma conditions at LEH (laser entrance hole)

NLUF interest is high-energy density plasma

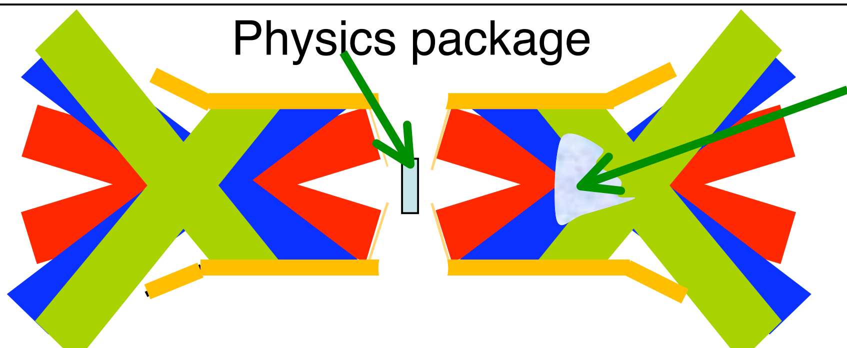


Plasma parameters:

n_e , $\langle Z \rangle$, T_e

Thomson scattering, Optical spectroscopy (Raman backscatter, Brillouin backscatter, Self-Thomson scattering, 3/2-ω spectroscopy), Au M-band X-ray spectroscopy, Time-integrated X-ray spectroscopy

Physics package can be developed in center of hohlraum without disturbing NLUF experiments



Plasma parameters:

n_e , $\langle Z \rangle$, T_e

We propose to add an experimental package in center of hohlraum, and add x-ray diagnostics for T_e, T_{rad} (“(n)LTE-meter”)